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Programmable Controllers

Multiple-Arm Control for Industrial Robots

Circle 50

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OCTOBER 1985 VOL. 7 NO. 10

EDITORIAL

FEATURES

DEPARTMENTS

About the cover: This month's cover photo, supplied by Allen-Bradley, was taken in the Robogate section of the Chrysler Mini-Van plant in Windsor, Ontario. The spot welding robots are supervised by A-B remote I/O stations coordinated by the PLC-3 programmable controller (see related article on page 11).

Robotics Is Not Just Concerned With Arms . . .

CARL HELMERS

Flexible Reprogrammable Manipulators are hardly the only components of applied robotics, or even the manufacturing part of the field of general robotics. We've seen much evidence of this of late. To our way of thinking, a true robot is a computer or set of computers applied as a real-time system to accomplish a non-trivial, practical real-world task. To engineer such a system we need sensors for machine perception. We need actuators to influence the world; these may in fact be conventional robot arm systems. The actuators can also be unconventional interactive outputs for humans or inter-machine communications. Voice or mechanical display methods come to mind when referring to human interactions. To complete the system picture, we need a real plan of action. Creating a system that accomplishes such a plan requires the concepts of functional modules and communications between them. This image of a robot as a system of sub-system parts is wider than the simple concept of the isolated robotic mechanism or numerically controlled tool. Putting the pieces together is the practice of robotics engineering.

Such engineering has come a long way—and it has a long way to go. Present technology is only part of an evolutionary process of design. Years ago, the first industrial slam-bang robots began to appear. The hard design of the mechanism defined the function it could do. Automation began. Design automation was non-existent.

At a later stage, we saw the beginnings of "flexible" robot arms. The ability to reprogram the mechanism to do different tasks instead of re-machining specialized materials handling mechanisms was a major step forward. A population explosion of such reprogrammable robots ensued. Flexibility and reprogrammability made them smarter. Limited communications protocols created on an ad-hoc basis allowed coordination of such arms with nearby machines. Mechanically, all the basic robotic mechanisms were determined early. Some major remaining design efforts are in the areas of end effectors, software and coordination of multiple automated devices, and design automation for robotic applications. These are areas where major design innovation is needed to carry forward pioneering efforts.

In this issue we have two articles concerning multiple arm control, evidence of innovation in the multiple device area. One, two, or several arms, viewed as a self-contained system, are but small pieces of major automated manufacturing systems being designed at present. Coordination of a small integer number of arms is one of the key components of industrial robotic automation as it is applied today. The issues to be addressed include communication, control, and the three-dimensional problem of overlapping work envelopes.

We recently had the good fortune to see a very practical working system which was an application of this multiple arm concept. This robotic system is a totally automated hard disk coating line of the Nashua Corporation in Merrimack N.H. In that company's newly automated factory, blank aluminum disks are fed into one end of a carefully choreographed line of multiple robot arms and specialized processing devices. The object of the process is to clean, then uniformly coat both sides of the aluminum platters with the magnetic material essential to these memory devices. We saw coordinated actions of five robotic arms in a live production coating line. The arms are key components of the larger process of creating a high quality product with human variability minimized through engineering and careful attention to the principles of statistical quality control.

To limit robotics to isolated manipulators is to limit the scope of what our new horizons of engineering can accomplish. The manipulator problem is largely solved. The arm portions of robotic systems will probably not assume any dramatically different configurations in the near future. The real progress will come in software, communications among various parts of our systems, and application of our increasing knowledge of artificial intelligence and uses of cost-effective computing resources. A robot—as intelligent machine—can be a factory, an automobile, a spacecraft, an undersea exploration device, a mining machine . . . and the list goes on. It is an automated contrivance of humankind used for human purposes. ■

Calendar

SEPTEMBER

30–4 October. Knowledge-Based Computer Vision. and Expert Systems: Applications in Robotics and Control. The Turing Institute, Glasgow, Scotland. Contact: George House, 36 N. Hanover St., Glasgow G1 2AD, Scotland, telephone (041) 552-6400.

OCTOBER

1–3. Dallas/Fort Worth Tool & Manufacturing Engineering Conference and Exposition. Infomart, Dallas, TX. Contact: Public Relations Dept., Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 293.

2–4. Developing Careers: Issues for Engineers and Employers. Royal Sonesta Hotel, Cambridge, MA. Contact: William R. Anderson, Institute of Electrical and Electronics Engineers, Washington, DC office, 1111 19th St., N.W., Suite 608, Washington, DC 20036, telephone (202) 785-0017.

8–11. FASTEC '85 Conference. Georgia World Congress Center, Atlanta, GA. Contact: Patricia Jones, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 377.

9–11. Robots East. Bayside Exposition Center, Boston, MA. Contact: Jeff Burnstein, PR Manager, Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

10–11. Expert Systems. The Royal Sonesta, Cambridge, MA. Contact: Jim Naphas, EFDPMA Conferences, c/o Technology Training Corp., Dept. EXSC, PO Box 3608, 3420 Kashiwa St., Torrance, CA 90510-3608, telephone (213) 534-4871.

10–13. Detroit Computer Showcase Expo™. Cobo Hall, Detroit, MI. Contact: Linda M. Yogel, PR Manager, The Interface Group, Inc., 300 First Ave., Needham, MA 02194, telephone (617) 449-6600.

10–13. Atlanta Computer Showcase Expo™. Atlanta Civic Center, Atlanta, GA. Contact Linda M. Yogel, PR Manager, The Interface Group, Inc., 300 First Ave., Needham, MA 02194, telephone, (617) 449-6600.

15–17. Developing Robot Workcells. Norcross (Atlanta), GA. Contact: Diane Korona, Program Administrator, Society of Manufacturing Engineers Special Programs Dept., One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 390.

15–17. The 4th International Conference on Flexible Manufacturing Systems. The 3rd International Conference on Automated Guided Vehicle Systems. The 6th International Conference on Automation in Warehousing. Alvsjo Trade Fair and Conference Centre, Stockholm, Sweden. Contact: IFS (Conferences) Ltd., c/o Stockholm Convention Bureau, Box 1617, S-111 86 Stockholm, Sweden, telephone (0) 8 23 09 90; or IFS (Conferences) Ltd., 35–39 High St., Kempston, Bedford MK427BT, England, telephone (0234) 853605.

16–17. Making the Decision to Invest in Advanced Manufacturing Technology. Clarion Hotel, Cincinnati, OH. Contact: Mary Lange, IAMS, 3220 Forrer St., Cincinnati, OH 45209, telephone (513) 841-8621.

17–18. National Conference and Exposition on Robotics and Automated Systems. Hilton Inn Bossier, Bossier City, LA. Contact: Dr. R. Michael Harnett, Meeting Chairman, Office of the Dean, College of Engineering, Louisiana

Calendar

Tech University, PO Box 10348 T.S., Ruston, LA 71272, telephone (318) 257-4647.

18–27. 1985 International Capital Goods Trade Fair. International Exposition and Trade Center, Cleveland, OH. Contact: Sandy Hensel, Director of Public Relations, 1985 International Capital Goods Trade Fair, 6200 Riverside Dr., Cleveland, OH 44135, telephone (216) 676-6000.

20–23. International Symposium on Laboratory Robotics '85. Boston Park Plaza Hotel, Boston, MA. Contact: Gerald L. Hawk, Ph.D., or Janet Strimaitis, Zymark Corp., Zymark Center, Hopkinton, MA 01748, telephone (617) 435-9501.

21–22. Programmable Controllers: The Basis of the 1985 Control Revolution in Factory Automation. Rensselaer Polytechnic Institute, Troy, NY. Contact: Ms. Lee Burgess, Management Development Programs, Rensselaer Polytechnic Institute, Troy, NY 12181, telephone (518) 266-6589.

21–23. Industrial and Commercial Applications of Artificial Intelligence. Kensington Town Hall, London, England. Contact: Lynn Brook, Queensdale Exhibition & Conferences, Blenheim House, 137 Blenheim Crescent, London, England, W11 2EQ, telephone 01-727 1929.

21–24. ISA/85 COMPUTEC. Philadelphia, PA. Contact: Fred E. Gore, Fisher Controls International, Inc., 8301 Cameron Rd., Austin, TX 78753, telephone (512) 834-7066.

22–23. Robot Justification Workshop. Chicago, IL. Contact: Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

22–24. SATECH '85: Systems & Applied Technology Conference & Exhibition. O'Hare Expo Center, Chicago, IL. Contact: SATECH '85, 2472 Eastman Ave., Bldg. 34, Ventura, CA 93003, telephone (805) 656-0933.

24–27. Chicago Computer Showcase Expo™. McCormick Place, Chicago, IL. Contact Linda M. Yogel, PR Manager, The Interface Group, Inc., 300 First Ave., Needham, MA 02194, telephone (617) 449-6600.

25–27. Forth Modification Laboratory (FORML). Stettenfels Castle, Frankfurt, Germany. Contact: Forth Interest Group, PO Box 8231, San Jose, CA 95155, telephone (408) 277-0668.

28–29. Grand Public Robotics Days. Amphitheatre Poincare, Paris, France. Contact: The French Association of Industrial Robotics, 61, Avenue du President Wilson—94230 CACHAN Paris, France, telephone (1) 547-69-33.

28–29. Automation Means Business. Hyatt Regency, Chicago, IL. Contact: Robotics Industry Service, Dataquest Incorporated, 1290 Ridder Park Dr., San Jose, CA 95131-2398, telephone (408) 971-9000.

28–31. ATE CENTRAL '85 Conference and Exhibit. O'Hare Exposition Center, Rosemont, IL. Contact: Registrar, ATE CENTRAL '85, 1050 Commonwealth Ave., Boston, MA 02215, telephone (617) 232-3976.

29–31. Laser Welding and Surface Treatment. Plymouth Hilton Inn, Plymouth (Detroit), MI. Contact: Dianne Leverton, Special Programs Division, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

NOVEMBER

1–3. Tampa Computer Showcase Expo™. Curtis Hixon Hall, Tampa, FL. Contact: Linda M. Yogel, PR Manager, The Interface Group, Inc., 300 First Ave., Needham, MA 02194, telephone (617) 449-6600.

4–7. AUTOFACT '85 Conference and Exposition. Cobo Hall, Detroit, MI. Contact: Tom Akas, Group Manager, Public Relations, Computer and Automated Systems Association/SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

6–8. Computer Integrated Manufacturing: Practical Applications in Your Plant. Washington, DC. Contact: Cliff Hopkins, Continuing Engineering Education, the George Washington University, Washington, DC, 20052, telephone (800) 424-9773 or (202) 676-8521.

7–10. Los Angeles Computer Showcase Expo™. Los Angeles Convention Center, Los Angeles, CA. Contact: Linda M. Yogel, PR Manager, The Interface Group, Inc., 300 First Ave., Needham, MA 02194, telephone (617) 449-6600.

12–13. Robot Control Systems Workshop. Cincinnati, OH. Contact: Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

12–14. Chicago Tool & Manufacturing Conference & Exposition. O'Hare Exposition Center, Rosemont, IL. Contact: Public Relations Dept., Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

13–15. Robot Assembly in the Electronics Industry. Orientation into Machine Vision. Robot Safety. (One day each.) San Jose, CA. Contact: Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

13–15 and 18–20. Machine Vision in Automotive Manufacturing: A Hands-On Clinic. Ann Arbor, MI. Contact: Joanne Rogers, SME Special Programs Div., Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 399.

17–22. 1985 ASME Winter Annual Meeting. Fontainebleau Hilton Hotel, Miami Beach, FL. Contact: Marisa Scalice, American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10016, telephone (212) 705-7053.

20. R & D Limited Partnerships Seminar. Robot Export Seminar. Detroit, MI. Contact: Robotic Industries Association, PO Box 1366, Dearborn, MI 48121, telephone (313) 271-7800.

20–22. Expert Systems Short Course. Monterey, CA. Contact: Continuing Education Institute, 10889 Wilshire Blvd., Los Angeles, CA 90024, telephone (213) 824-9545. (To be repeated 4–6 December in Columbia, MD.)

20–24. COMDEX/Fall. Las Vegas Convention Center, Convention Center's West Hall, The Hilton, Riviera, Caesar's Palace, and MGM Grand Hotels; Las Vegas, NV. Contact: Peter B. Young, The Interface Group, Inc., 300 First Ave., Needham, MA 02194, telephone (617) 449-6600.

DECEMBER

11–13. Second International Conference on Artificial Intelligence Applications. Fontainebleau Hilton, Miami Beach, FL. Contact: Artificial Intelligence Applications, PO Box 639, Silver Spring, MD 20901.

MULTIPLE-ARM ROBOT CONTROL SYSTEMS

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105 Delta Drive
Pittsburgh, PA 15238

Can you tie your shoelaces? What if you were blindfolded and wearing workgloves? How would it go if you and a similarly encumbered friend both tried to tie a single pair of shoelaces, you using your right hand and your friend his left? Given the primitive state of vision and tactile sense technologies, this is where practical robot control stands today. While coordination between multiple arms in a truly human fashion is still in the future, there are nevertheless multiple-arm systems not quite so exotic but that perform useful tasks not readily accomplished by single-arm systems.

The thought of multiple robot arms brings with it images of great, complex control problems. This certainly can be true. However, many multiple-arm systems, such as some assembly lines, are really rather straightforward, with each arm doing a task relatively independently or with relatively little communication with the world around it. We will not discuss these simpler tasks. We will examine instead some practical examples of multiple-arm robot applications involving highly integrated systems or very close coupling. We will then address some general issues and considerations in practical multiple-arm systems, the International Cybernetics Corporation (ICC) 3200 Flexible Automation Controller (FAC) used in these applications, and the specific control approaches used to create an operational, cost-effective system.

THREE EXAMPLES OF MULTIPLE-ARM TASKS

Example 1: A two-arm lathe loader. A manufacturer of horizontal turning machines (metal lathes) has added a robot loader. The loader picks an unmachined part out of a pallet or off a conveyor belt, loads it into the chuck of the lathe, retrieves the part after it has been machined, and places the part back in the correct location in the pallet or on another conveyor. These parts can weigh up to 500 pounds. They are handled by both arms operating synchronously and sharing the load. To save handling (and lathe inactivity) time, the arms operate separately, one arm doing the chucking and the other the unchucking operation. To avoid machine damage due to operator error, the loader must prevent the arms from colliding with the housings and lathe supports. The working envelope varies, depending upon the specific lathe on which the loader is installed. Each arm consists of an axis that swings the arm in one plane, an "extend" axis that controls the length of the arm, and a rotating wrist plus a gripper. The arms ride together laterally across the front of the lathe on a track called the carrier (Photo 1).

Example 2: A two-arm robot press loader/unloader. An automobile manufacturer wants to use a robot to transfer sheet metal parts (such as fender linings) from one metal stamping press to the next in a press line. Speed is very important; a press cycle takes about 5.5 seconds. In that time a robot must be able to pick up a freshly stamped part, insert it in the next press in the line, approximately 15 feet away, and get back to the first press for a new part. A single general-purpose robot can't do the job fast enough; two, on the other hand, take up too much floor space and are too expensive. The solution is a two-arm robot with arms at 180 degrees to each other on a common swivel base (Photo 2). With this configuration, by the

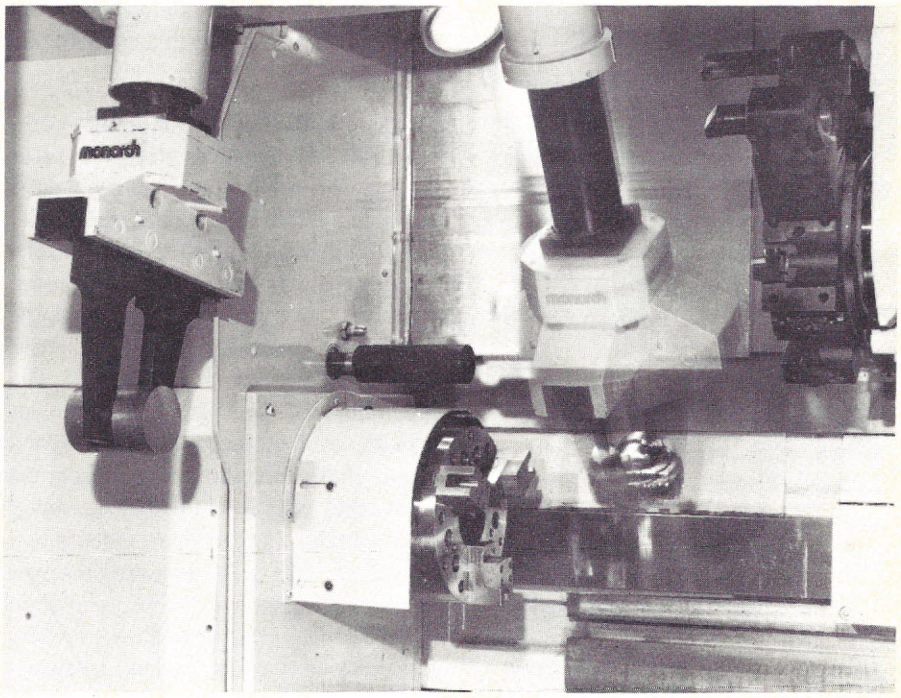

Photo 1. A Monarch Sidney two-arm lathe loader picks an unmachined part out of a pallet or off a conveyor belt, loads it into the chuck of the lathe, retrieves the part after machining, and places the part back in the correct location in the pallet or on another conveyor.

time one arm has handled a part, swung around, and placed it in the next press, the second arm is already in position for the next part. A major problem, though, is finding a robot control system that can more difficult, the robots are very light and susceptible to vibrations, as are the sheet metal parts they are holding. Motion must therefore be both very fast and extremely gentle.

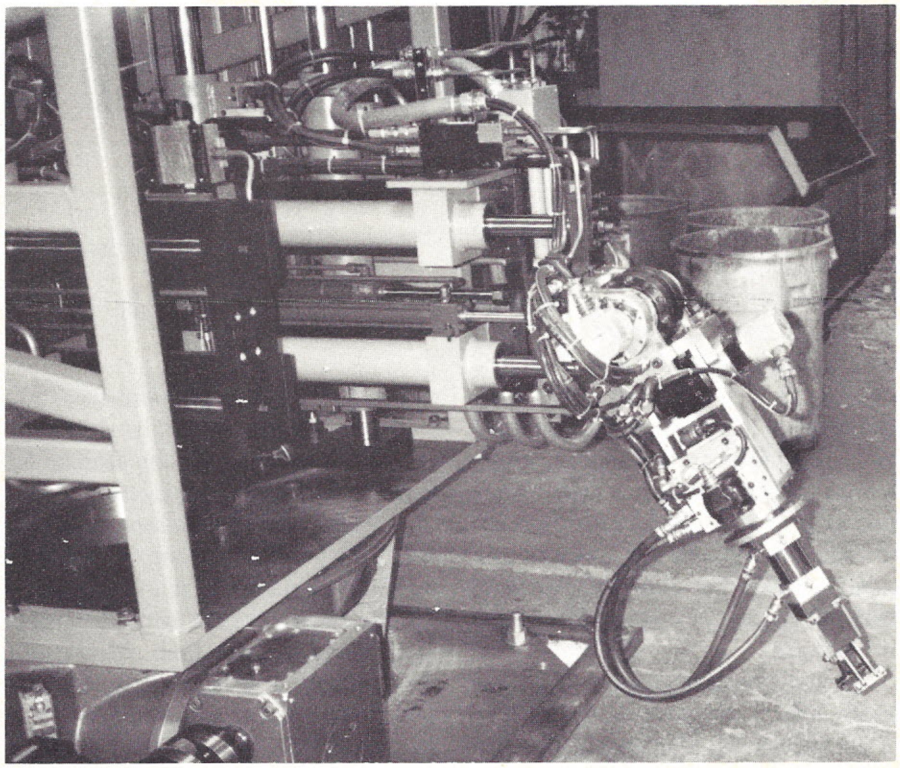

Photo 2. The two arms of a Bra-Con press loader/unloader robot are 180 degrees apart on a common swivel base. By the time one arm has handled a part, swung around, and placed it in the next press, the second arm is already in position for the next part.

handle 13 axes of motion. A typical industrial robot controller handles only six axes.

Example 3: Two single-arm robots working together to handle stamping press loading and unloading. This problem is basically the same as in the first example, but a different approach is used, involving two two-axis robot arms. Each robot operates in a vertical plane in line with the center of the stamping press. One arm is on either side of the press (Photo 3). The first robot picks up a part from a conveyor and places it in the press. The second robot removes the stamped part from the press and places it on another conveyor. As is usual on a factory floor, speed is very important. The customer wants the new part to be inserted in the press as soon as possible after the old one is removed—and without a collision. Due to delays elsewhere in the press line, the unloading speed may change during a cycle or even come to a stop. To make the problem even

SOME PRACTICAL MULTIPLE-ARM SYSTEMS CONSIDERATIONS

The preceding examples represent real industrial applications problems. They share a cost sensitivity, as well as unique design requirements that preclude general-purpose robot arms. For many tasks it is far less expensive to design a specialized robot with the exact characteristics required for the job than it is to use a standard robot that lacks required reach, speed, or weight handling capabilities while possessing other features that will go unused.

A number of issues need to be considered in multiple-arm installation:

The job to be done. A solid understanding of the job and of the problems that can arise is often the key to the simplest system design for the task at hand. On the subject of problems in control system design, it is often not overly difficult to keep a production line running. The major problems

tend to arise when the system is being started up, stopped, or, of course, when something completely unforeseen happens.

Workspaces. Shared physical workspaces necessitate collision avoidance, a requirement made more difficult by the lack of good vision systems. Even with vision, collision avoidance may require a knowledge of the other robot's "intentions" to completely avoid accidental contact. Brute force collision avoidance tends to require a lot of mathematics and communications, putting severe resource strains on a system. There is therefore much to be said for minimizing or eliminating the conflict potential. Alternately, in many cases, the collision avoidance problem can be adequately dealt with by simpler one- or two-dimensional approaches that are tailored to the control problem.

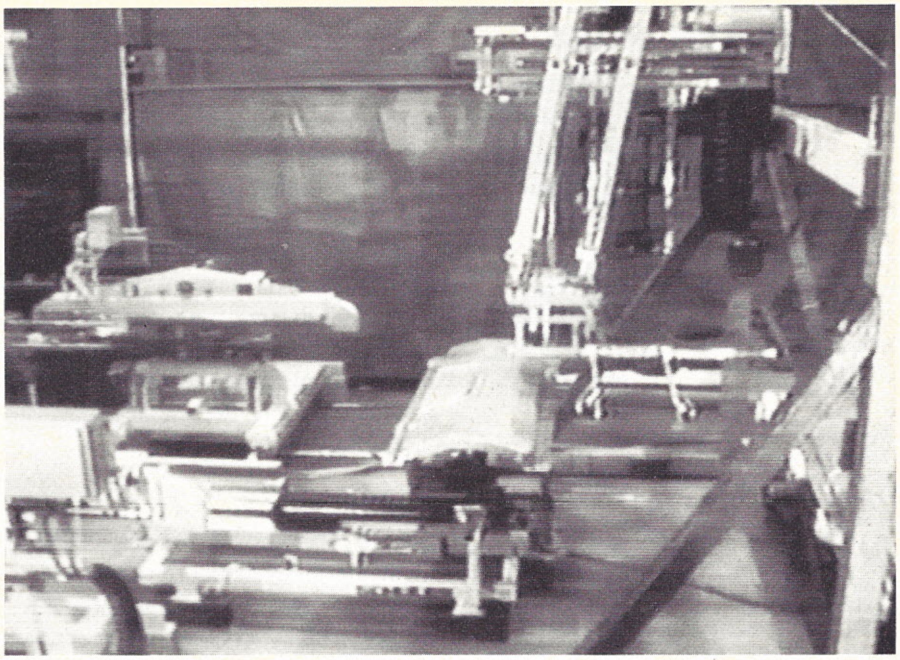

Photo 3. Two Schuler single-arm robots work together in a sheet metal stamping press operation. The first robot picks up a part from a conveyor and places it in the press. The second robot removes the stamped part from the press and places it on another conveyor. The robots are stationed on opposite sides of the press.

Task Coordination. Whether robots share a work envelope or not, multiple-arm systems require an understanding of the task coordination involved. As illustrated by the hypothetical shoelace maneuver, in addition to worrying about colliding with your friend's fingers and arms, there is also the problem of motion coordination. This requires communications.

Communications. Systems that do not share a brain have a communication problem. One solution is that each unit know and be able to perform its portion of the task so perfectly that all parties can just assume the entire operation is being carried out without flaw, an assumption fre-

quently made in real-world multiple-arm systems. Even though robots tend to be rather precise about their work, this assumption is not always valid.

In many systems, workspace movement, task coordination, and communications can be handled by systems as simple as handshake or status signals that indicate conditions such as clear/not clear or go/no go. A prime determinant of task coordination capabilities is the tightness of control and communication between arms. This rests heavily on the robot controller capabilities.

THE ICC 3200 AUTOMATION CONTROLLER

The previously described custom robots use a single type of general-purpose flexible automation controller, the ICC 3200. Before taking up how the actual control systems were implemented for these applications, a short discussion of the FAC is in order.

The ICC 3200 is a complete multiprocessor, hierarchical, distributed processing industrial control system. It was not designed specifically for robotic applications, but rather handles them as one type of automation application. It combines a supervisory system controller microprocessor with up to eight axes of highly integrated digital motion control plus input and output lines for handling discrete external devices such as solenoids, switches, and lights. The bus-structured philosophy with a multi-slot enclosure enables the user to configure the system in the best combination of axis modules and options required to accomplish the task at hand.

Each axis of motion is controlled by a separate axis module with its own dedicated microprocessor. This axis module operates as a complete, high-performance, closed-loop motion controller whose entire operation is transparent to the user. It requires only an appropriate motor amplifier and a single motion transducer to control AC electric, DC electric, or hydraulic servos from 1/5 to 300 horsepower.

To make the fullest possible use of the microprocessor's capabilities, every possible physical component in the axis module was replaced with software, which is cheaper and more reliable. Software's digital precision also makes possible simple, direct control of servo parameters never before accomplished. This patented technology is called direct numeric processing, or DNP for short.

DNP requires only a single reliable brushless resolver (rotary transformer) to digitally generate all feedback. Both position and velocity feedback loops are closed in software, including all servo compensation and gains. This process eliminates all analog circuitry except for the resolver-to-digital converter and a simple digital-to-analog output converter. This approach results in a system with only about one-third the electronic components of conventional servos.

Due to its rate loop integration and compensation algorithms, DNP systems are immune to drift and DC offsets in the motor power controller. Gains, bandwidth values, current monitoring, and current limits can all be set digitally by means of software commands from the system controller. These are analogous to adjustment potentiometers but with certain advantages: they do not drift; they can be set to precise, repeatable values instead of requiring subjective tweaking sessions; and they permit perfect matching of dynamic characteristics in multi-axis coordinated systems such as robots. Additional system controller-to-axis module commands control parameters such as position, speed, several types of acceleration, and torque.

Internally, the system measures position with an internal resolution of 16,384 parts per revolution with a total range of 260,000 revolutions. For ease of use and computation, the user can set the effective resolution to any convenient value, such as 1000. The system, however, always uses the larger value internally for the highest possible accuracy. Conversions between internal and external resolution are handled transparently.

In line with the distributed processing philosophy of the controller, the DNP servo takes responsibility for axis-level fault handling and detection by constantly checking its servo system for fault conditions such as drive fault, feedback failure, stall or runaway, excess average torque, and both hardware and programmable end-of-travel limits. When a problem is detected, the axis controller takes appropriate action and also informs the system controller, which can then execute the safe machine shutdown or recovery procedure the system implementor has designed specifically for the machine. This

philosophy substantially reduces overhead in the system controller processor.

The entire system's operation is supervised by the system controller, which manages the motion control sequences, the monitoring of inputs and outputs, and communications with the axis modules. Interface modules allow the system controller to communicate with the outside world via serial interfaces for use with CRT displays, data entry systems, printers, and networks.

All high-level software at the system controller level is written in a proprietary dialect of BASIC called CYBER-BASIC. ICC chose BASIC as the starting point for a programming language because of its universality and the ease with which it can be used. CYBER-BASIC is a special implementation of BASIC optimized for machine control. It is very complete, with a toolbox of 220 commands available—145 for general use and 75 for motion handling and machine control. This large command set minimizes programming time and program size by providing many powerful machine control commands. The language is available in both compiled and interpreted implementations and each type in both ROM and disk versions. Virtually all high-performance automation control applications are written using the compiled ROM implementation. This creates a dedicated machine control in which the CYBER-BASIC roots of the control program are invisible.

The following are examples of CYBER-BASIC machine control-oriented commands:

Motion:

INDEX	move an incremental amount
MOVETO	move to an absolute position
START	start a continuous move
SPEED	change the speed of a move
PROFILE	perform the motion profile previously stored in the axis
SETCAM	turn the cam table mode on or off

Interface:

GETIN	check control inputs
SETOUT	update control outputs

Adjustments:

SETRPG	set the rate loop proportional gain
SETRES	set the axis resolution
SETATC	set the acceleration time constant
SETPOS	set the axis position

Information:

GETPOS	read the current axis position
GETSTAT	obtain the current axis status
GETTIME	read the system timer

CONTROL APPROACHES USED IN CONTROL SYSTEM EXAMPLES

Example 1: The two-arm lathe loader. This example represents a fairly simple two-arm control problem. The fact that the two arms either operate completely synchronously or perform tasks one at a time puts a manageable control load on a single-system control processor. With a total of fewer than eight axes for both arms, it is possible to implement the entire system in a single ICC 3200 chassis. This approach is extremely cost-effective, provides the required capabilities for two arms, and simplifies the arm and task coordination problem by having a single "brain" supervising all tasks. This is analogous to a human's using his own two arms for a task. Collison avoidance between the arms and the lathe housing is implemented by programmable zone boundaries along the linear carrier axis with programmable limits for each axis within a zone.

Example 2: The two-arm robot press loader/unloader. First impressions call for a separate control system for each robot arm. This, however, creates task coordination and communications problems between the arms and would force users to contend with two sets of user interfaces, making the two-armed unit difficult to program. A far simpler solution is to have a single controller handle both arms. The result resembles the lathe loader robot problem. Since only one robot arm is busy at a given time, the workload on the supervisory processor is not excessive. The major problem for the designers lay in finding a robot controller that could handle 13 axes. ICC combined two 3200s in a tightly coupled master-slave relationship. The six axis controllers for one arm plus the rotating base axis controller are housed in the master's chassis, and the six axis controllers for the other arm are in the slave chassis. A combination serial and parallel communications system and command protocol links the two systems, allowing the master to send commands to the slave and the slave to inform the master of its operating status and to advise of any problems. The master-slave relationship of the two chassis is hidden from upper levels of the control software and the user interface so that the whole machine is programmable as a single two-arm robot. This approach greatly simplifies operator use and problem diagnosis.

The master-slave relationship represents a looser level of control that is more remote than direct. As a result, system throughput drops from that of a single system due to the communications overhead. In this specific case, system throughput is still quite acceptable. Because this system is operating in real time and controlling a large, potentially dangerous machine, fail-safe operation even during malfunctions and lost communications is imperative.

This particular master-slave arrangement performed so well that it was later used on a non-robotic automation applica-

tion involving 32 axes plus 8 axis-level master-slave motion synchronizing boards called sync-ratio cards for a total of 40 axis control boards spread over five 3200 chassis.

Example 3: The two single-arm robots working together to handle stamping press loading and unloading. In this case, both loader arms are operating asynchronously so each arm has its own chassis and controller. The arms share a workspace inside the press. In order to maximize the throughput, the customer wanted the loader arm to insert a new part as soon as possible after the withdrawal of the old part. This created a collision avoidance problem. Because a new part cannot be loaded until the old part is unloaded, collision avoidance is essentially a one-way street—the loader must avoid the unloader. Also, because we are interested in collision avoidance and not in close interworking, the collision avoidance problem can be looked at as a one-dimensional game of "chicken" between loader and unloader. Collapsing the problem from three dimensions into one greatly reduces the complexity of the task, making it possible to trim the amount of position data transferred and processing on that data by encoding the entire horizontal travel (approximately 9 feet) into an 8-bit (one byte) code. In this scheme, the loader knows the unloader's position within half an inch, more than adequate for collision avoidance. The position data is sent and read via parallel data ports. Because the two robots are running asynchronously and the data can be updated and read at any time, a gray code was used to transmit the position data.

A gray code is a binary number sequence that changes in such a manner that only one binary digit (bit) is modified at a time when a value is incremented or decremented by one. With a simple binary coding scheme, if the loader were to read data simultaneously with the unloader writing it, the loader might see a combination of changing bits that indicated an arm position substantially different from the correct one, with potentially disastrous results. By changing only one bit at a time, a gray code eliminates this possibility.

Knowing its distance from the unloader arm, the loader arm calculates a speed for itself such that even if the unloader arm halted, it has enough distance between it and the unloader that it could come to a gentle but optimally fast stop. By constantly calculating its speed on this basis, the loader can follow very close on the heels of the unloader without colliding with it or putting excessive force on the arm.

CONCLUSION

We have looked at three approaches to handling multiple-arm robot systems. These are real industrial applications that strive less at generality than at solving the required problem expeditiously, efficiently, and economically. Until robotic and sensor technology improve to the point that other solutions are practical, these represent some approaches that wring as much performance as possible out of the existing technologies.

Phil Chimes is director of automation products at International Cybernetics Corporation.

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PROGRAMMABLE LOGIC CONTROLLERS SPEARHEAD FACTORY AUTOMATION

Janie West
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Today's VLSI microprocessor and memory chips, together with their solid-state electronic relatives, are helping to set the pace for incremental factory automation. Programmable logic controllers (PLCs) with advanced microchips at their cores are spearheading the trend toward distributing computer-based intelligence throughout the factory floor. Such "smart" machines are synonymous with distributed control, which places the necessary amounts of memory and processing power at strategic factory locations to execute control, monitoring, and data gathering on the spot.

Hence, PLCs at the grass roots level are instrumental for automating both today's factories and tommorow's. Unlike the first PLCs that performed only simple ON-OFF functions for sequential control, the new breed has evolved into rugged, versatile, and sophisticated control and information-collection devices that are used in virtually all industries.

Basically, PLCs are microprocessor-based controls that accept, evaluate, and process inputs, and generate appropriate outputs to control machines or processes. Like any other microprocessor-based computing system, a PLC consists of a central processing unit (CPU), memory, and input/output (I/O) sections. Its memory stores data and instructions. The instructions direct the CPU to perform such functions as logic, sequencing, timing, counting, and arithmetic upon the data. These processing functions then control various types of equipment and processes through digital and analog I/O modules.

PLCs are high-performance dedicated computers designed for use in the sometimes harsh electrical and physical environments of the factory floor. They are programmed with tools such as hand-held programmers and video programming units that feature a specially designed language, relay ladder logic, as well as troubleshooting, maintenance, and documentation capabilities. This rugged design, ease of use, and flexibility of use, plus solid-state reliability characterize all

TABLE 1
Categories of Programmable Logic Controllers and Their Key Features

Controller Type	Cost	Memory Size	Capability	Programmability	Maintenance Diagnostics	Communications	Operations Interface	Hot Backup
Micro	$250 to $1000	1K or less	Fixed 32-128 I/O Limited Instruction Set-12	Relay Ladder Logic	None	RS-232 for Programming	Checking Logic Only	No
Small	$500 to $5000	1-4K	Configurable 8-512 I/O 25 Instructions	Relay Ladder Logic	Light Indicators Built-in Self-check Logic	Network	Report Printouts Only	No
Mid-Size	$5000 to $10,000	Up to 16K	Configurable 8-2K I/O 40 Instructions	Relay Ladder Logic HLL, BASIC	User-developed Diagnostics	Network	CRT Terminal or Printer	No
Large	Up to $20,000	Up to 2 Meg	Configurable 8-8K I/O 50 or more Instructions	Relay Ladder Logic HLL	User-developed Diagnostics	Network	Color Graphics Terminal or Printer	Yes

PLCs, regardless of size. PLCs are offered in several sizes, each suited to particular applications. Furthermore, add-on intelligent modules, operator interfaces, and factory networks are coming off the drawing boards and going into the factory in quantity.

DIFFERENT PLCs

Table 1 shows four major PLC categories and their salient features. Microcontrollers, priced from $250 to $1000, have fixed I/O, a limited relay-like control with no math capability or upper-level functions, and no more than 1 Kword of memory. The resulting control capability provided is minimal by today's standards. Generally, microcontrollers are low-cost relay replacements whose futures are limited to non-networked applications. (Network interfacing of hardware and software costs more than these microcontrollers themselves.) An RS-232 programming port is the only communications capability microcontrollers have. Notwithstanding these limitations, the smallest PLCs are likely to continue being used as stand-alone devices in small shops. Their greatest future potential application could be as imbedded control elements.

The smallest controller, based on sequencers that cost about as much as a complete microcontroller, provides from 8 to 512 configurable I/Os. These small PLCs with upwards of 25 instructions provide addition, subtraction, multiplication, and division, while other instructions manipulate bits for direct control. Small controllers have 1 to 4 Kwords of memory and can often be connected to a PLC network.

As shown in Table 1, a major difference between a small controller and a mid-sized one is sequencing speed. Mid-sized controllers generally use faster sequencers than small controllers. The cost of mid-size PLCs ranges from $5000 to $10,000, depending on configuration. They feature I/O that is expandable from 8 to 2000 points, plus integer and floating-point math. Floating-point math provides considerably greater dynamic range than do simple integers.

Mid-size controllers also feature higher level instruction sets with upwards of 40 instructions, including high-level math and diagnostics. Their up to 16 Kwords of memory can accommodate larger and more complex programs and data structures, and they can be networked. Moreover, they offer remote I/O capability. This feature allows I/O modules to be moved away from the sequencer so that the control sensing interfaces can be distributed closer to the sites of execution. Other features include PID loops for loop control, and, in addition to relay ladder logic, programming can be done in a process language or a high-level language such as BASIC.

As Table 1 shows, sequencer configurablity is the most distinguishing feature of a large controller. Also, many hardware options are available as plug-in modules. With these, a system can be configured by mixing and matching modules. This is often the most cost-effective approach to control needs. Older, less flexible PLCs forced users with only discrete requirements to pay for built-in PID capabilities useful only in continuous control. Today, large controllers have hardware options that encourage factory management to apply control dollars more effectively by targeting solutions to the problems at hand.

Large controllers have 50 or more instructions. Words can be manipulated and ASCII code generated within the sequencer itself, thanks to the enhanced instruction set. In these PLCs, memory can grow up to two megabytes. Besides supporting the PLC's primary function of control, the larger memories also provide archiving capability and help gather and store diagnostic information at the PLC level. Moreover, large controllers often can communicate upwards in the plant-information hierarchy.

The differences among various levels of PLCs are particularly apparent in the area of self-contained testing and maintenance capabilities. Microcontrollers have virtually no indicators to alert operators of impending failure. Small controllers display the state of the sequencer via indicator lamps and flags. Many times, internal self-checking logic informs the operator of the total PLC's state of health. Mid-size controllers have enough memory to generate diagnostics for the control process. Large PLCs often have enough memory to store response-processing capability along with the diagnostics.

A PLC acts as a programmable sequencer. By using sensor-derived inputs, the PLC develops its output control from functional programs previously entered by control engineers. When the appropriate output line is scanned, the PLC actuates the required outputs to provide the actions dictated by its stored program. Figure 1 shows the four main functional blocks, programmer, sequencer, input, and output.

Distributed industrial control is now providing systems solutions to extend these and other important functions. Industrial systems can now communicate with one another through networks. Many different brands of PLCs often are connected at the machine level by such data highways as TIWAY I. Figure 3 shows that distributed control can be extended even further, taking machine levels into micro levels. In this example, process "A" is controlled by one machine. "Intelligent" subsystems that incorporate sequential control, complex math, or bar code inputs can implement micro control.

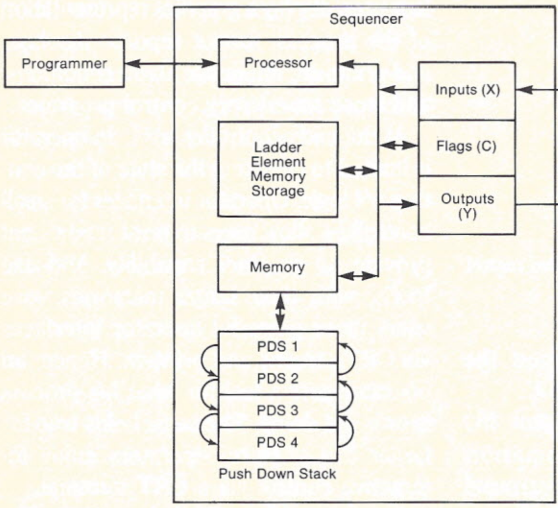

Figure 1. The programmable logic controller's four main functional blocks are the programmer, the sequencer, input, and output.

PLCs scan a predetermined number of I/O points. The actual sequence of reading the input, solving the control sequence based on the input conditions, and then setting the outputs accordingly is executed on a fixed time cycle. Scan time may vary from 1 to 2 milliseconds per 1000 words of program to up to several hundred milliseconds. The speed depends upon the type and quantity of I/O modules and the computation requirements of the user's program. Scan time, the speed at which a PLC can execute its relay ladder logic program, is critical for fast-response operations (Figure 2).

Hence, scan rates limit a PLC's processing power and functionality. Controllers, therefore, often need help when such control functions as ASCII messaging for alarms and data logging, complex math for machine diagnostics, motion control, and specialized interfaces are needed in addition to the routine control jobs that usually consume most of a PLC's memory and scan time.

Control systems often require fast responses for specific functions such as halting a rotating machine after a specific number of revolutions. Moreover, due to the increased number of I/O points and the fact that memory size has increased significantly, scan times have come under

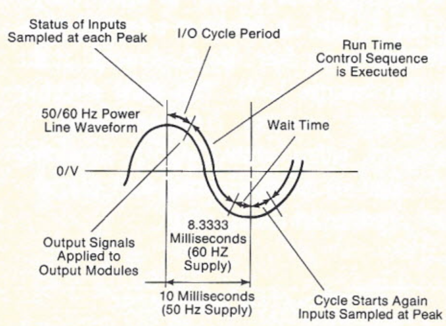

Figure 2. Programmable logic controller scan time is the major limiting factor for achieving fast-response operations.

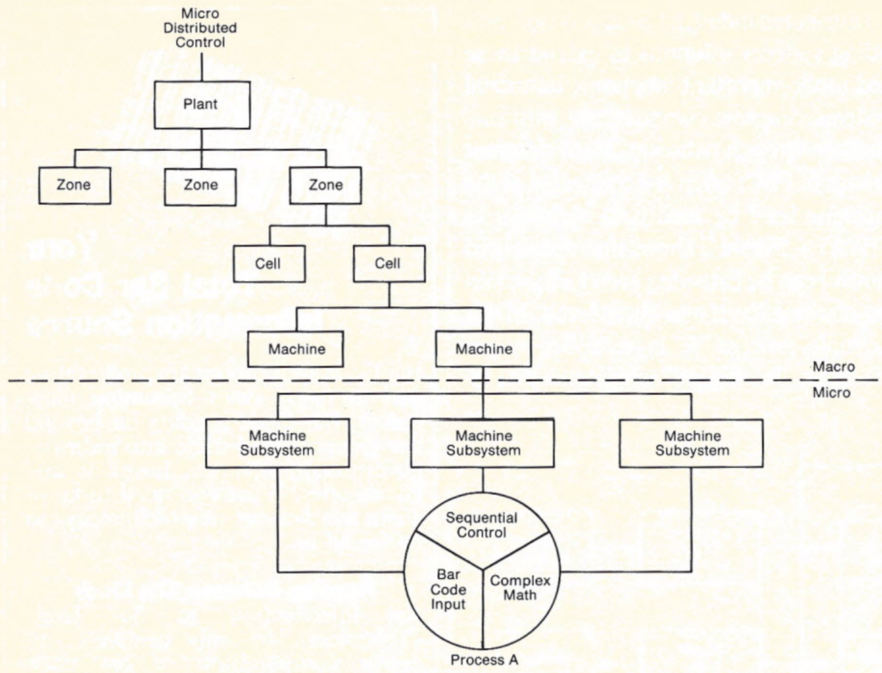

Figure 3. Adding intelligent subsystems that perform control and support functions extends distributed control to the micro control level in the factory.

pressure to run faster. An effective solution has been to concentrate more intelligence at the I/O points. This alleviates the PLC's scan-time and memory burdens. Such modules often can take control action on their own, independently of the PLC scan and at the precise moment it is required. The module then reports the action it has taken back to the PLC.

Fortuitously, intelligent I/O has come to industry at a time when diagnostics, supervisory control, faster scan times, and operator interfaces have become recognized aids that can help increase plant productivity. Intelligent I/O is a modular solution that allows plant managers initially to omit unnecessary functions, thus eliminating their costs and complexity. As control system requirements grow, further distributed control can be implemented with intelligent I/O modules.

These new forms of I/O have evolved from earlier I/O module technologies. Some require only simple hardware to do their tasks. Most, however, use complex microchips including microprocessor and advanced memory chips. These modules' key attributes include fast response times, on-board memory, redundancy, easy programming, operator interface, communication ports, and network connectivity. They also include many self-diagnostics that detect failures within their own systems. Peripheral device failures are detected as well, since the I/O modules report the faulty equipment back to the PLC.

Programmable BASIC intelligent I/O modules provide the automation capabilities needed to perform carousel logistics: servo-axis modules perform auto inserting and extracting, while programmable BASIC and ASCII message output modules, respectively, execute auto-identification and report generation. A bar code reader attached to the front end of the wave-soldering machine reads the codes on the printed circuit boards being processed to the BASIC module. The BASIC module at that location goes into the PLC memory and gathers the actual process parameters so it can print production reports on a board-by-board basis.

Before intelligent I/O, the functions now handled at the micro level were executed at the top control levels at much higher cost. Adding an operator interface gives the user a window into the process at the micro control level. The most effective operator process communication is through video control panels providing detailed visual information that can also be produced in hard copy.

OPERATOR INTERFACES

Traditionally, the simplest form of man-machine interface has been the lighted pushbutton. Such an approach is not adequate for today's PLC-based factory systems that collect vast amounts of information to inform databases about the processes. Operators must have access to this information so they can make intelligent decisions and take action. Thus, operator interfaces are key features to a factory's smooth operation. Peripheral devices such as CRT monitors, printers, industrial terminals, loop-access modules, and timer-counter access modules provide local operator interfaces to the PLC. Intelligent operator interfaces also can help operators to communicate with PLCs. Such interfaces can display a graphics representation of the process; format reports, displays, and printouts; enunciate alarm conditions; and store supervisory control programs.

At the microcontroller level, an operator is limited to checking the state of the controller's logic. Operator interfaces for small controllers allow users to print reports but provide no graphics capability. Mid-size PLCs, with their larger memories, give users more powerful operator interfaces via CRT screens and printers. Hence, an operator gets a feel for what his process is or is not doing. The same holds true for larger PLCs. Here, operators enjoy interactive control via a CRT terminal.

A color graphics display terminal, like TI's CVU5000, shown in Photo 1, is an

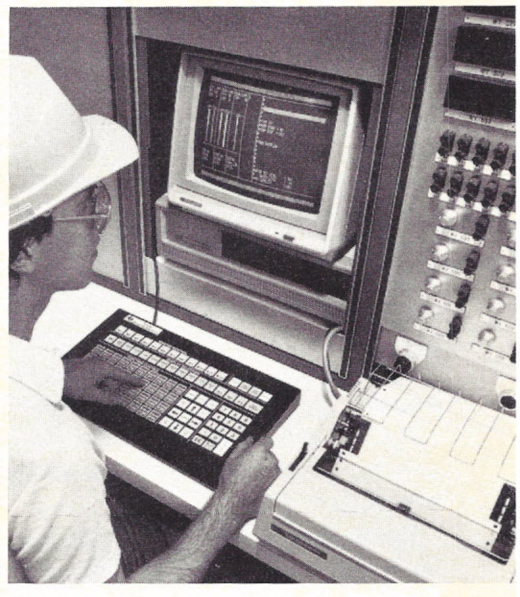

Photo 1. A color graphics terminal, such as the Texas Instruments' CVU5000 shown here, is an effective user/system interface in applications involving large amounts of data. The operator can command the control vision unit (CVU) to segregate information and bring onto the screen data of immediate interest. Selective viewing of data helps avoid the sensory overload that can trouble operators confronted with a vast array of electromechanical control devices.

especially effective and low-cost user/system interface in applications involving large amounts of data. The operator can command the control vision unit (CVU) to segregate information and bring onto the screen data of immediate interest. Nested levels of displays—from general overview pictures to specific graphic details—allow the operator to view the process in whatever detail and at whatever level is appropriate at the moment. The ability to view data selectively helps avoid the problem of sensory overload, which often plagues operators confronted with electromechanical (EM) control panels covered with dials, gauges, thumbwheels, switches, status lamps, and other measurement devices.

An engineering keyboard is the focal point for entering control functions in most CVUs. Set points, time and counter settings, process variables, loop data, and other control information can be entered quickly and easily via the keys. Because each key is dedicated to a single control function, even operators who are totally inexperienced on a keyboard can quickly become proficient. Also, CVUs easily accommodate an auxiliary printer output, so appropriate control events can be reported on hard copy. It is more costly and not so easy to get hard copy from EM control panels. These need expensive auxiliary ASCII out peripherals to print out reports, which in turn raises system costs significantly. Rigidly designed and inflexibly built EM control panels do not lend themselves to the fast changes and turnarounds effective factory management demands today. On the other hand, thanks to their highly reliable solid-state technology base, CVUs inherently possess the flexibility needed to achieve quick, inexpensive changes in a modern production facility.

TYING PLCs TOGETHER

As information-gathering devices, PLCs are helping to bring networks into modern factories. PLCs, networked with communications systems, are emerging to allow various factory areas to electronically share valuable manufacturing information. Industrial local area networks (LANs) are important to factory management simply because manufacturing productivity demands fast and efficient transfer of production status information to and from mainframes and among distributed processing devices such as PLCs. Networks provide error detection, correction, and addressability, which is becoming critical as the number of computers within a factory increases. From PLCs, networks can gather alarm, quantity, parts count, rate, and time information. Moreover, they centralize data relating to alarm monitoring, report generation, quality control monitoring, and maintenance dispatch. LANs also faciliate sharing such expensive resources as printers, storage devices, operator interfaces, and, of course, the information itself.

LANs help decentralize factory control, giving management the important option, when a plant is being expanded, of choosing small, well-planned increments instead of large, costly, and cumbersome ones. Ultimately, for higher level decision making, LAN-derived information can make an entire factory appear to be a single integrated process. Networking gives factories the tools to avert trouble by making timely changes. Data made available through LANs can warn of potential problems before they escalate to costly and even unmanageable situations. In particular, historical data can be used to forecast such occurrences as worn machine parts or times when systems are likely to slow down or speed up.

Figure 4 shows a typical LAN composed of one or more CPUs interconnected by a communications link with an assortment of peripheral devices and storage units. Different topologies, network-access methods, and routing techniques are associated with LANs. All PLC LANs, however, are characterized by low-to-medium data throughput, operating distances from a few yards to miles between processors in single or multiple buildings, and single-organization ownership.

The three basic LAN topologies, or patterns of interconnection among the various computing devices tied to a network, are bus, ring, and star (Figure 5). A bus links each control node via a central transmission line. Messages sent down the line pass by each node but not through it. In this topology, a node can fail and not cause network disruption. In a ring, all nodes are linked into a continuous chain with all messages going through each node. The greatest disadvantage of a ring topology is the high probability of total system disruption when one node fails. The star

topology features a central node that routes all messages among its surrounding nodes. The star pattern is acceptable for PBX-type network communications. However, network operation depends completely on the central node's reliability. If it goes down, the entire network collapses. Hence, of the three, the bus has distinct advantages in LANs using PLCs as secondary nodes in the factory.

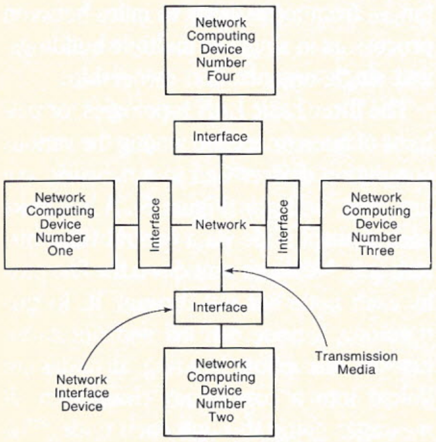

Figure 4. A typical industrial local area network consists of one or more central processing units interconnected by a communications link with a variety of peripheral devices and memory storage units.

LANs combine hardware and multiple levels of software to communicate data among control nodes. Hardware includes: 1) a transmission medium such as shielded, twisted wire; baseband and broadband coaxial cable; or fiber-optic cable; and 2) a network interface module in the PLC or other factory computer connecting it to the LAN cable.

LAN programs consist of a set of software protocols implemented in all factory components and PLCs connected to a network. These protocols are communication conventions that allow two or more LAN end points to speak a common language. These end points can be PLCs, terminals, peripheral-device controllers, operator interfaces, application-specific computers, or host computers.

LAN protocols include a set of well-defined messages and the rules for their exchange. Protocols specify addressing that always includes the message destination. Additionally, the following information may be included in a transmission: source name, error controls to detect and recover from errors, flow control related to buffering capacity, data for synchronization or management of the communication path, and the state of the remote communicating activity.

A key ingredient involving LAN hardware and software is the need for standards that allow the nodes to communicate effectively. LAN standards permit disparate equipment types to communicate with each other, simplify the task of developing compatible software, and reduce the cost of networks by promoting the development of a variety of standard and interchangeable components. Several different organizations are actively involved in drafting standards for LANs. Among them is the IEEE Project 802 committee that is drafting standards for CSMA, token-bus, and token-ring topologies; logical link control; and high-level interfaces. Also, the International Standards Organization has already established a seven-layer model called the Open Systems Interconnection (OSI).

As more industrial users are learning, no one network can solve all application needs. However, many users are selecting networks that both fit jobs at hand and can be expanded to meet future needs. The networks chosen are being judged on how well they connect to other LANs to make sure that they will retain their connectivity under future network standards.

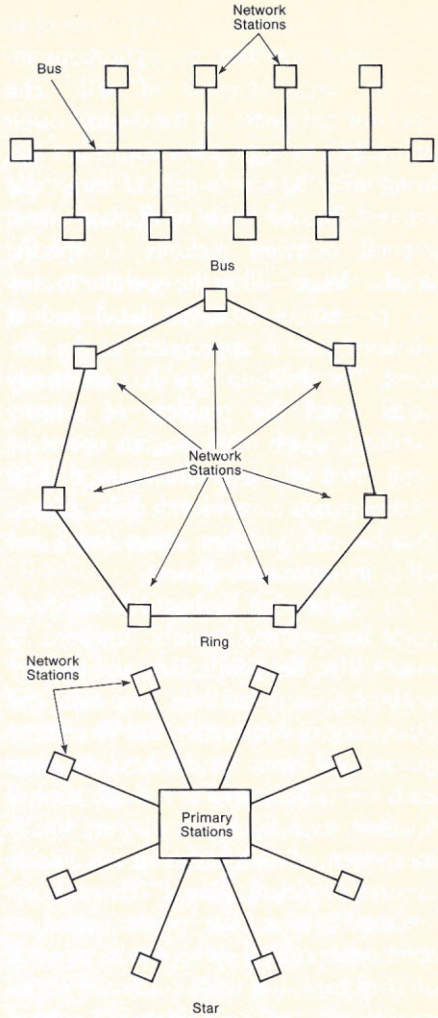

Figure 5. The three network topologies are the bus, the ring, and the star. For factory local area networks, the bus pattern is the most reliable and offers distinct advantages over the other two patterns.

MANUFACTURING AUTOMATION PROTOCOL

The Manufacturing Automation Protocol (MAP), currently being developed by General Motors, has drawn considerable attention as a viable approach to digital communications between computers and intelligent control devices on the factory floor. MAP shows promise because it will be implemented by many vendors, thereby ensuring a variety of compatible equipment from many sources. The specification is based also on existing and emerging OSI standard protocols, assuring that anyone can obtain the information needed to produce or use MAP-compatible equipment.

MAP's objective is to tie together various types of systems and equipment supplied by different vendors. This goal is a prerequisite for GM's long-range factory automation plans. Those plans look toward a factory using various types of equipment, all working together to complete a coordinated manufacturing task. A secondary goal is reducing the costs of communications cabling.

The MAP protocol is still evolving. Significant capabilities, such as network management and configuration, remain to be defined before MAP produces user-friendly systems. For the non-GM user, MAP is perhaps best viewed as an important experimental network. In several years, however, most users of automated manufacturing equipment will feel some effects of Manufacturing Automation Protocol.

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AN INTELLIGENT DATA ACQUISITION CONTROLLER

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San Gregorio, CA 94074

Although any computer with access to an I/O port can be used to monitor voltages, many applications require constant scanning and quick response. Since many control processes are written in BASIC or a higher-level language, they are often too slow to scan a number of variables and respond in time. For this reason, the CY600 Intelligent Data Acquisition Controller was designed to perform this scanning function with minimal cost, effort, and design time. The CY600 easily interfaces to an 8-bit I/O port, or, with a CY250 front end, the CY600 can be driven from a serial I/O line. These two basic configurations are shown in Figure 1.

The CY600 can be used with 8-bit, 12-bit, and 16-bit analog-to-digital converters. The corresponding resolutions are one part in 256, one part in 4096, and one part in 65,536 respectively. If you assume that an 8-bit A/D converter is used, then the full scale reading is 256, while the minimum reading is zero. For a 16-bit A/D converter, the full scale voltage is measured as 65,535. If the maximum measured voltage is 10 V, and the minimum is 0 V, then the resulting measurements are accurate to voltage variations on the order of 150 μV. Since the price of the converter usually depends on the resolution, most applications use the smallest number of bits that will suffice.

Regardless of the measurement resolution employed, the CY600 will generate five-digit ASCII integers suitable for use in any BASIC program (or any other language, of course). A command of the form *!A<CR>* is used to read a voltage into the CY600. This command causes the CY600 to perform all the handshaking necessary to convert a voltage reading into a digital value stored in Register A of the CY600. To determine what value is stored in Register A, the host computer simply sends the query command *?A<CR>* to which the CY600 responds with a five-digit ASCII integer and a carriage return (such as 00359<CR>).

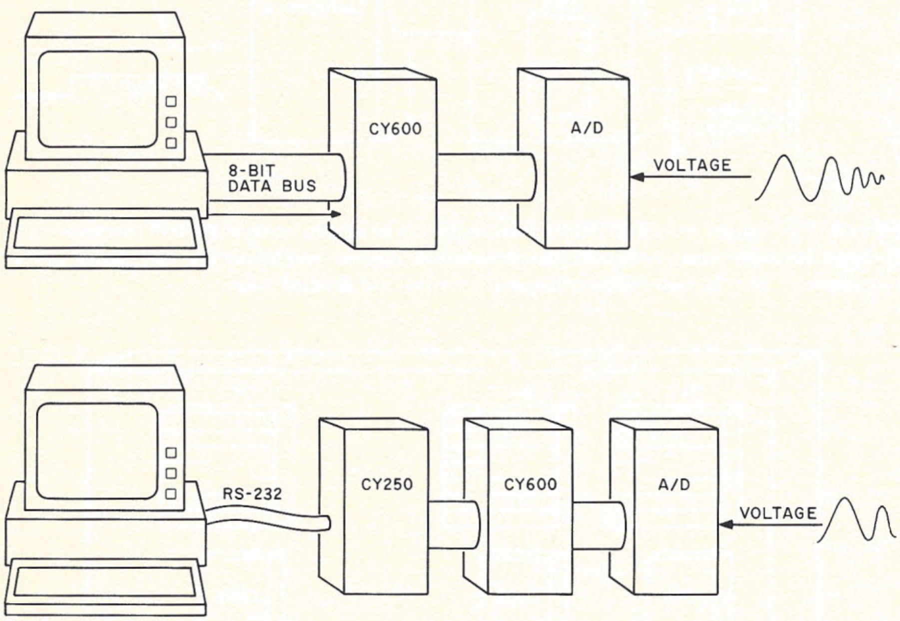

Figure 1. The CY600 can be easily used in a parallel or serial communication mode. The parallel interface can easily be connected to any microcomputer with 8-bit I/O ports. The addition of a CY250 provides a voltage monitoring system that will work with serial communications based on RS-232 protocol.

CHANNEL CONFIGURATION

Register A described above is one of several registers residing in a CY600 *channel.* The CY600, arranged in a minimum configuration, contains five data registers per channel named A, B, C, N, and T. This set of registers is called the *register file.* The CY600 is commanded to read a voltage value into any register (x) by using the command: *!x<CR>.*

In addition to the register file, each channel also contains a *code buffer* in which a simple data acquisition program may be stored and executed. For example, the following channel code or program can be used to scan a voltage and test it against a given threshold, say 245:

!A ; A>245<CR>

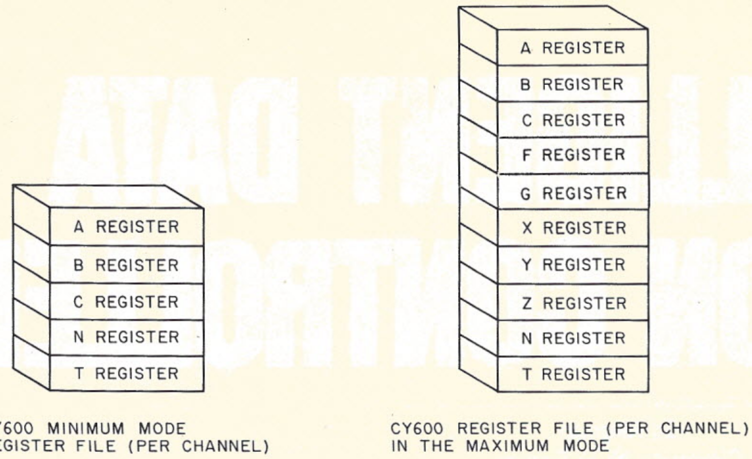

Figure 2. The number of data registers per channel depends on the chosen CY600 setup configuration. The minimum configuration allows five registers per channel. The maximum configuration provides eight registers per channel but requires external memory for data storage.

This example program consists of two simple commands. The first command, *!A*, reads the voltage into Register A. The second command, A>*245*, tests to see if the value in Register A exceeds 245.

The semicolon separates the two commands. The carriage return, *<CR>*, terminates the command string. If this program is stored in channel zero, you can enable the program by using the command *E0<CR>*, and issue the command *E<CR>* to start the scanning process for all enabled channels.

To summarize, you can command the CY600 to monitor a voltage and report when the voltage exceeds a threshold value of 245 by sending the ASCII character strings:

!A ; A > 245<CR>
E0<CR>
E<CR>

The CY600 generates a signal when the voltage exceeds the defined threshold. This signal can be used to interrupt the computer and allow it to take appropriate action, or it may simply activate (or deactivate) a particular peripheral system. For instance, the signal may turn off a heater when the temperature crosses the threshold. The response from the CY600 is immediate (within microseconds). The signal line remains active until the computer has seen it and responded. The complete system cycle is shown in Figure 3.

Each channel on the CY600 consists of a register file and an associated code buffer. Data is stored in the register file and tested according to the program in the channel buffer. It is called *a channel* instead of *the architecture* because the CY600 architecture consists of several channels. The actual number varies from one to four depending on the mode or configuration in which the CY600 is set up. Each channel is a duplicate of the others. However, the channels operate completely independently. For all practical purposes, the multiple channels can be viewed as multiple copies of a CY600. The complete CY600 architecture is shown in Figure 4.

The channels are like several CY600s in another way. They are scanned *concurrently*. That is, you may assume that the programs in each of the channels are executed simultaneously. This allows you to repeatedly test multiple conditions much faster than is possible with high-level languages and much more easily than can be done with assembly language.

SELECTING CHANNELS

The command *#n<CR>* is used for selecting a particular channel in the CY600 (*n* is the channel number). Thus, the command *#0<CR>* selects Channel 0 and *#1<CR>* selects Channel 1.

The demonstration program can be extended to demonstrate this ability. Assume Channel 0 is to be used to detect when the voltage exceeds 245 and Channel 1 is to be used to detect when the voltage falls below 165. The command sequence for executing this program is given in Listing 1. This command sequence causes the

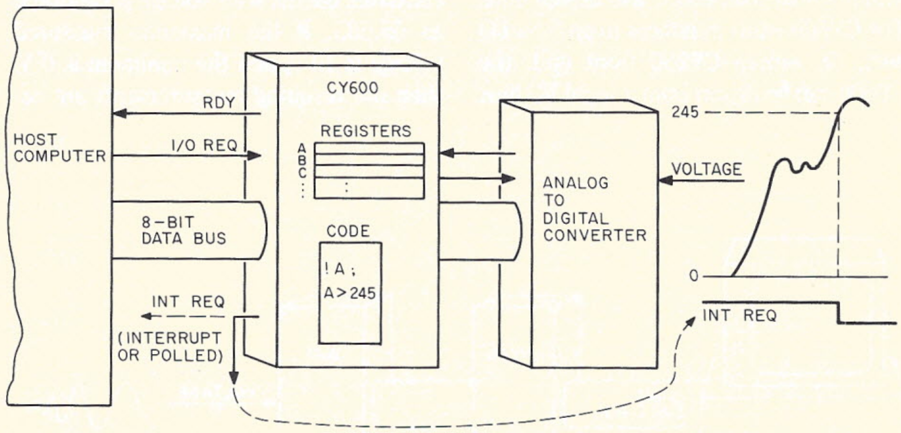

Figure 3. The interrupt request (INT REQ) line (pin 35) can be used to interrupt the host computer when the target condition occurs, or it can cause an immediate response and remain low until cleared by the host computer after the host computer has polled the line and detected it low.

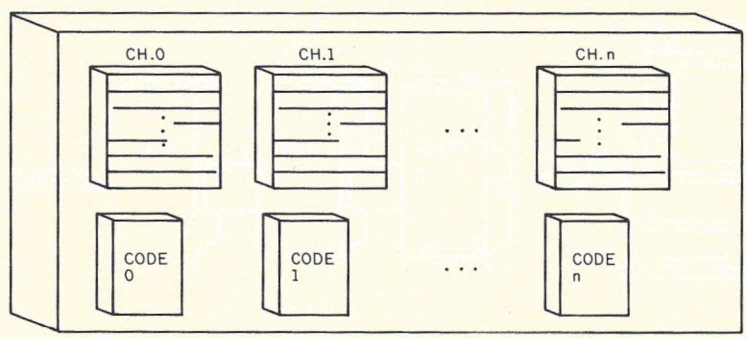

Figure 4. The CY600 architecture consists of several independent channels with identical copies of channel register files and channel code buffers, but with unique data and programs in each channel.

ROBOTICS AGE BACK ISSUES

SUMMER 1979: Digital Speed Control of DC Motors; Industrial Robots '79; Introduction to Robot Vision; The Grivet Chess-Playing Arm. **(photocopy)**

WINTER 1979: Advances in Switched-Mode Power Conversion, Part 1; Prospects for Robots in Space; Robotics Research in Japan, Report from IJCA16.

SPRING 1980: Microcomputer Based Path Control; Robotics Research in France; Multiple Sensors for a Low-Cost Robot; the Robots of Autofact II; Inside Big Trak.

SUMMER 1980: Industrial Robots; Today and Tomorrow; Introducing the Minimover 5; Advances in Switched Mode Power, Part II.

FALL 1980: Using Optical Shaft Encoders; Interview with Victor Scheinman; Robot Vision for Industry; The Autovision System; Industrial Robotics '80; Robots on Your Own Time; Superkim Meets ET-2.

MAR/APR 1981: Video Signal Input; Chain-Code; Camera Geometry for Robot Vision; TIG Welding with Robots; Robot Digestive Track—Robots on Your Own Time.

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Listing 1. A simple demonstration program using two channels to test for high and low voltage conditions.

```
COMMAND              COMMENT
#0<CR>               select channel 0 for commands
!A ; A>245<CR>       read the voltage into register A and test A>245
#1<CR>               select channel 1 for commands
!A ; A<165<CR>       read the voltage for register A and test A<165
E0<CR>               enable channel 0 for scanning
E1<CR>               enable channel 1 for scanning
E<CR>                enable scanning mode
```

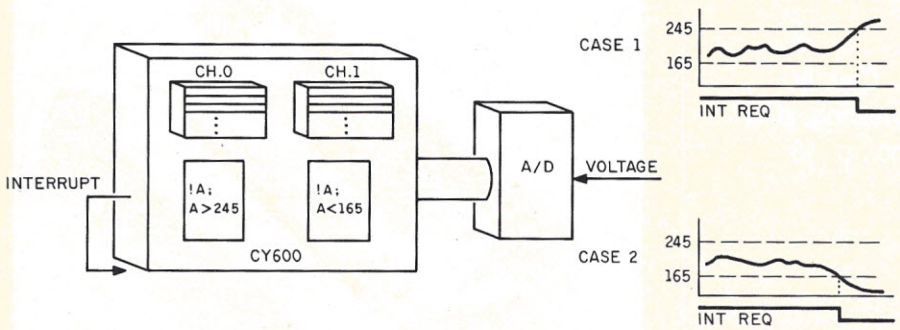

Figure 5. Two or more channels can be scanning for independent conditions simultaneously.

CY600 to execute both channels simultaneously and respond when either condition occurs, as shown in Figure 5.

Each channel has a register named A that is referred to simply as A in the code for the specific channel. When you use a command to read a voltage into Register A or read a value out of Register A, the commands apply to Register A of the selected channel.

Instead of always issuing the channel select commands to reach the different registers, you can use a channel suffix to identify the desired channel. Thus *?A0* reads Register A in Channel 0, while *?A1* reads the contents of Register A in Channel 1.

CONDITIONAL EXECUTION

The test condition commands can be used to control whether certain portions of the code are executed. For example, consider the following command sequence:

!A ; A>245 ; R0<CR>

In this case, the third command, *R0*, executes only after the condition has evaluated *true*. The channel code will cycle as long as the value in Register A is less than 245. If the value of Register A exceeds 245, then the commands following the test are executed. The particular command shown, *R0*, resets (drives low) one of the eight general-purpose I/O lines on the CY600.

Conditional execution allows you to extend the previous example to derive a simple controller. In the earlier version, the same output line was driven low when either condition occurred. This output is the dedicated signal line designed to interrupt the host computer and its behavior is predetermined. You can use one of the eight general-purpose I/O lines to indicate that a specific event has occurred. In this example, you can add two conditional commands as shown in Listing 2.

The *Sn* command sets (drives high) I/O line *n* and is the inverse of the *Rn* command. The action of the two new commands is shown in Figure 6. The I/O line is driven low when the value of A exceeds 245 and then driven high when the value of A drops below 165. If the voltage is considered to represent a temperature, then the I/O line might be used to turn a heater on and off to maintain the system temperature in a desired range.

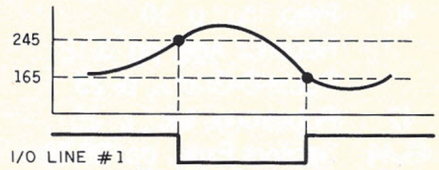

Figure 6. The *Sn* and *Rn* commands can be used to set and reset a general-purpose I/O line to control an external device or communicate with the controlling computer. This example, controlled by the program in Listing 1, shows a general-purpose I/O line being reset low when the voltage goes over 245 and being set when the voltage measurement goes under 165.

CROSS-CHANNEL CORRELATION

To specify a particular channel during a register read operation, you must either select the channel via a *#n* command or add the channel number as a suffix to the register name. The channel suffix is a general mechanism that applies any time a register name is used. If a suffix is not used, the channel always defaults to the current channel being commanded or scanned. The presence of a suffix overrides the current channel and forces access to the named register in the specific channel. This ability is very useful in our example program.

The current example program reads the measured voltage value into Register A of Channel 0. The same voltage is immediately sampled again and read into Register A of Channel 1. Since you can safely assume that the temperature will not change in microseconds, this second voltage measurement is performed merely to make the temperature measurement available in Channel 1. You can access the voltage measurement in Channel 0 without having to read it into Channel 1 by using the suffix feature. The program that accom-

Listing 2. A modification of the demonstration program using conditional execution techniques and driving a status line.

```
COMMAND                  COMMENT
#0<CR>                   select channel 0
!A ; A>245 ; R0<CR>      read voltage, turn off heater if >245
#1<CR>                   select channel 1
!A ; A<165 ; S0<CR>      read voltage, turn on heater if <165
E0<CR>                   enable channel 0 for scanning
E1<CR>                   enable channel 1 for scanning
E<CR>                    enable scanning mode
```

Listing 3. This version of the demonstration program only reads the voltage once. The second sampling channel reads the voltage value from the first channel.

```
COMMAND              COMMENT
#0<CR>               select channel 0
!A ; A>245 ; R0<CR>  read voltage into A0 and test >245
#1<CR>               select channel 1
A0<165 ; S0<CR>      see if voltage in A0<165, set line 0 if true
E0<CR>               enable channel 0 for scanning
E1<CR>               enable channel 1 for scanning
E<CR>                enable scanning mode
```

plishes this is shown in Listing 3. This code is equivalent to the version in Listing 2.

DATA TRANSFERS AND MATHEMATICAL OPERATIONS

All the above examples have used the *!A* command to read data into Register A from the analog-to-digital converter. Data can also be transferred into a register from another register. A colon (:) denotes the transfer operation. The colon operator can be used to transfer information from one register to another or to load a register with a specific value. For example, the command *A : 180<CR>* loads Register A with the value 180. The command *A : B<CR>* loads Register A with the contents of Register B. The contents of Register B are not altered.

The four basic mathematical operations (addition, subtraction, multiplication, and division) can also be used to manipulate register values. For example, the command to add 10 to Register B and place the result into Register A is simply *A:B+10<CR>*.

Mathematical operations can also be used with test conditions. The command *A>B+10<CR>* tests to see if the value in Register A exceeds the value in Register B by 10. Once you understand the transfer and compare operations, you can use any valid mathematical relations in your commands. For example:

A : ((B + C) / 3)<CR>
N : N + 1<CR>
*C > ((A−B) * N)<CR>*

In all cases, the expression on the right is evaluated first, and the result is transferred to the target register or compared with the target register on the left as appropriate. Parentheses are used to establish precedence, otherwise the usual precedence applies: multiplication and division are performed prior to addition and subtraction. Since the data consists of positive integers, any fractional result is represented by zero.

CY600 I/O STRUCTURE

The CY600 pinout is shown in Figure 7. The 40 pins include the 8-bit data bus, the handshake lines to the host computer, the handshake lines to the analog-to-digital converter, and the eight general-purpose I/O lines that can be set, reset, and tested by the channel code. Special lines include the reset line from the host that resets the CY600 and the interrupt line that informs the host when any conditional test evaluates true. Finally, the 5 V power and ground lines and the two clock lines complete the group.

The CY600 is designed to interface to standard 8-bit I/O ports at TTL levels and to standard analog-to-digital converters.

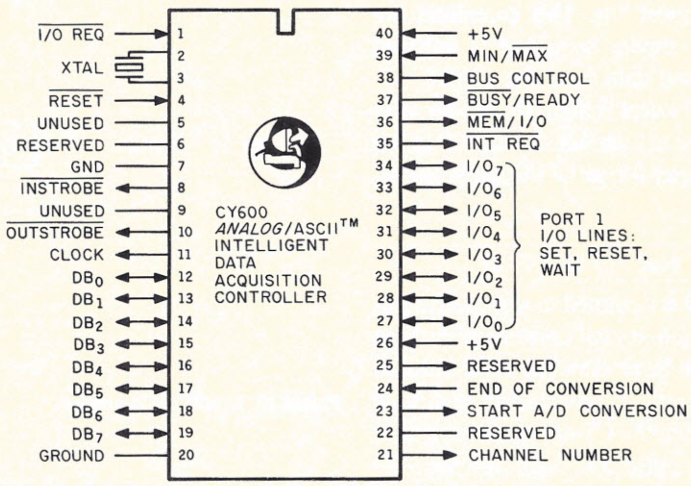

Figure 7. CY600 pin configuration.

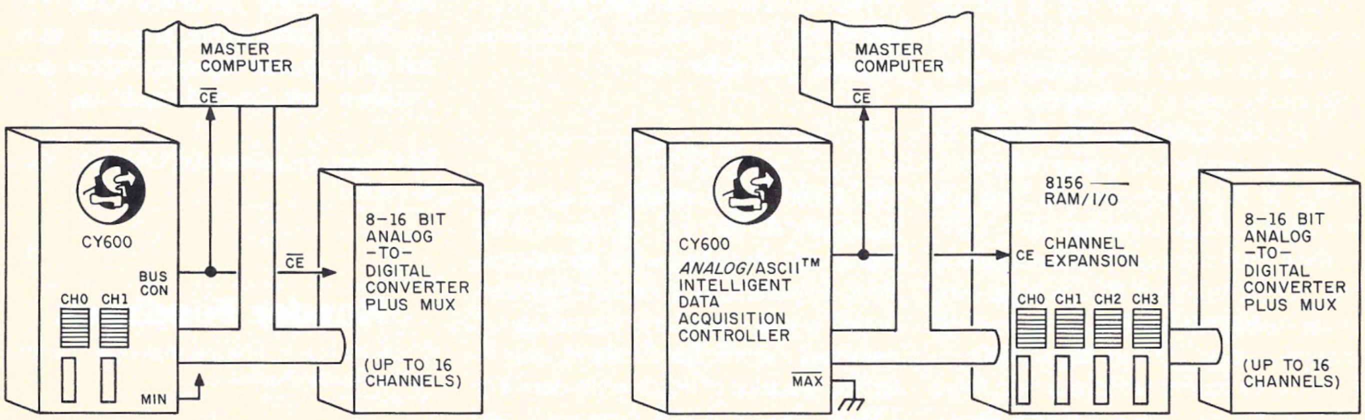

Figure 8. The CY600 minimum and maximum configurations. The maximum configuration requires an external memory chip for data storage.

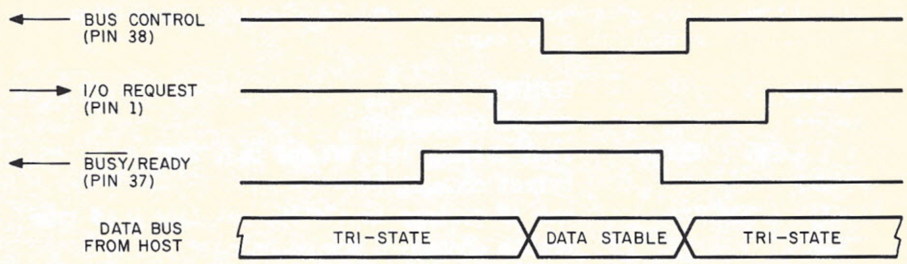

Figure 9. Interface timing for data transfer from the host computer to the CY600 control chip.

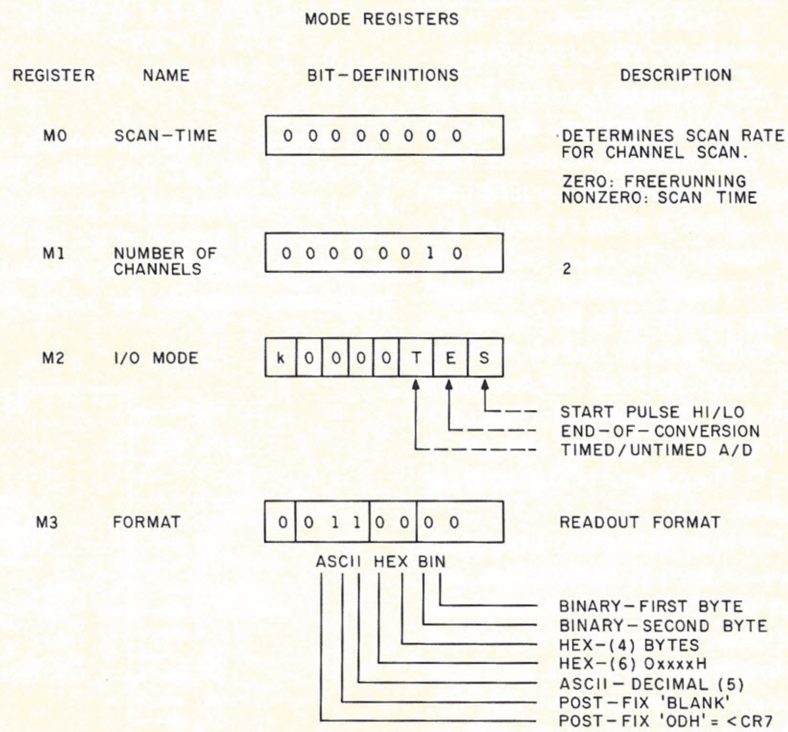

Figure 10. CY600 mode registers.

The CY600 may be used in two different configurations as shown in Figure 8. These are the minimum and maximum configurations and determine the number of available channels, the size of the register file in each channel, and the I/O structure.

In both configurations, the 8-bit bus is shared between the host computer port, the CY600, and another chip. In all cases, the CY600 acts as the traffic cop that controls the data flow on the bus. To send or request information from the CY600, the host computer waits for the BUSY/READY signal to show READY, then asserts the active low I/O REQUEST line to the CY600.

The interface timing diagram is shown in Figure 9. When the bus control signal is low, the host can place the desired data on the bus. The host should maintain its port in the high impedance state except when the bus control is low. After placing the data on the bus, the host waits for the BUSY/READY pin to go low (BUSY) indicating that the CY600 has accepted the data. The host then brings its port back into the high impedance state and raises the I/O request line. This completes the transfer. A similar sequence is followed when reading data from the CY600.

A CY250 Local System Controller chip may be used to interface the CY600 to the host computer for serial I/O applications.

CY600 A/D INTERFACE

The CY600 is designed to work with standard analog-to-digital converters such as the National Semiconductor ADC 0816. In response to the *!* command to read data into a register, the CY600 produces a start conversion pulse and waits for the A/D converter to signal with an end of conversion (EOC) signal. The default values are a positive start pulse and a low going end-of-conversion signal. If this is not appropriate for the particular A/D converter that you wish to use, then a mode register (M2) can be used to produce the required A/D interface handshake. The bit map for this mode register and others is shown in Figure 10. Mode register *n* is loaded with any value, *k*, via the command *Mn,k<CR>*.

The CY600 possesses a 4-bit output port and an 8-bit input port (16-bits in the maximum configuration). The ports share the general-purpose I/O lines already defined. Data can be transferred to and from these ports by treating them as registers. For example the command *A : I* reads eight bits into the lower Register A. The command *01 : 5* sends 0101 to port 1.

The output port is normally used to control an analog multiplexer to select various voltages while scanning.

SUMMARY

The CY600 is designed as a voltage monitoring device to offload work from the microprocessor and allow the microprocessor to do useful work while the CY600 continuously scans and tests the voltages. It possesses a simple handshake for easy interface to analog-to-digital converters. The CY600 accepts ASCII commands and returns ASCII voltage values; however, it can also return binary values if these are preferred. Scanning approximately 1000 times per second, the device is suited for monitoring temperature, pressure, strain, and other physical variables, and can react quickly to any detected conditions.

Ed Klingman is president of Cybernetic Micro Systems.

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ASSEMBLY ROBOTS WITH OVERLAPPING WORK ENVELOPES

Brian Wade and Roger H. Clarke
Gulf+Western
Advanced Development and Engineering Center
101 Chester Road
Swarthmore, PA 19081

Multiprocessing robot controllers that can simultaneously carry out multiple tasks are not readily available at the present time. Although they are highly efficient machines, those that are available are high priced, which has tended to make their justification difficult. Fortunately, many of the advantages of multiprocessors can be simulated by the proper selection, programming, and interfacing of multiple single-arm robots.

At the recent Robots 9 show in Detroit, Michigan, Gulf+Western Advanced Development and Engineering Center (ADEC) displayed a multi-arm cell that combined three dissimilar robots. The exhibit was designed to demonstrate Gulf+Western's ability to implement a sophisticated three-robot workcell with overlapping work envelopes.

The multi-arm cell used an IBM 7535, a Seiko PN-700, and a Hitachi PW10 to randomly assemble and disassemble 10 amp and 20 amp circuit breakers. The cell layout is shown in Figure 1. The IBM robot performed the assembly, the Seiko robot performed a part transfer, and the Hitachi robot disassembled and returned the parts to the feeders.

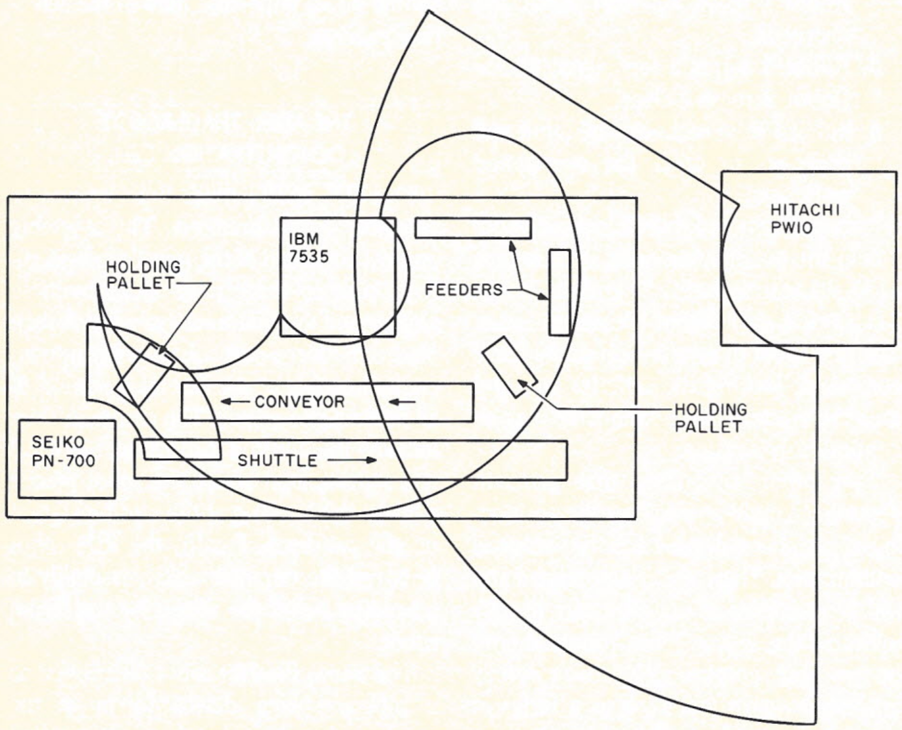


Figure 1. Gulf+Western's three-robot workcell, demonstrated at this year's Robots 9, used dissimilar robots made by three different companies to assemble and disassemble circuit boards. The IBM 7535 performed the assembly, the Seiko PN-700 performed a part transfer, and the Hitachi PW10 disassembled the breaker and returned the parts to the feeders. Notice the overlapping work envelopes.

ADVANTAGES OF MULTI-ARM CELLS

A properly designed assembly workcell with two or more robot arms and overlapping work envelopes can have significant advantages over single-arm cells or successive robotic cells on an assembly line. For instance, a two-arm overlapping cell can save as much as 50 percent of the factory floor space needed for an equivalent two-station system. Additionally, a multi-arm cell can cut costs by reducing material handling equipment and positioning fixtures and by simplifying safety guarding. Part sensing needs are likely to be reduced because less handling decreases the risk of mispositioned parts.

Another significant advantage of a multi-arm cell is faster cycle time. The parts and the robots have shorter distances to travel; there is at least one fewer indexing step; and both robot arms can be working on

the same workpiece at the same time, all of which reduce the cycle time.

OVERCOMING DIFFICULTIES

While advantages of multi-arm cells are appealing, several difficulties must be overcome to fully maximize the benefits. These include collision avoidance communication, information transmission, peripheral equipment positioning, and workload optimization.

The most important of these difficulties, but the easiest to solve, is collision avoidance communication (CAC). CAC is necessary to avoid robot arm collisions in the overlapping portion of the work envelopes. This communication can be performed using a simple handshake routine. A handshake routine between two robots is accomplished by using one input/output (I/O) port from each controller to communicate the robot's status. Each additional robot arm added to the cell requires an additional I/O pair to be assigned from each of the other robots it overlaps.

A handshake between two robots is performed as follows:

1. Robot 1 checks for input from Robot 2 output.
2. If Robot 2 is clear of Robot 1, it will have sent a high signal (1).
3. Robot 1 reads the high signal and proceeds.
4. Robot 1 sends a low signal (0) for Robot 2 to stay clear.
5. Robot 1 then rechecks the input and proceeds to enter the overlapped work area.

It should be noted that as long as Robot 1 is in the overlapping area, it maintains a low signal to Robot 2. Therefore, Robot 2 stays clear until Robot 1 leaves the area. The first robot to send a high signal takes command, locking the other(s) out, and thus the master-slave relationship may be continuously shifting.

Two other difficulties that arise in designing a multi-arm cell are the positioning of peripheral devices and the workload optimization. These are closely related and will be discussed as one. In order to fully optimize the system, both robots should be working continuously. By carefully analyzing each robot's job as a series of subtasks and by carefully planning the system layout, the operating time of each robot can be maximized. For instance, by positioning the parts feeders for Robot 1 and Robot 2 in non-overlapping areas of the cell and placing the part positioning device in the center, Robot 1 can be busy placing parts while Robot 3 is busy picking up parts. If the workload analysis shows that Robot 1 will force delays into the cycle of Robot 2, subtasks can be reassigned to Robot 2 to balance the work load, other conditions permitting. In the previous example, proper design will provide that both robots will be working at the same time, while poor design could result in unnecessary waits by either or both robots.

The final difficulty that must be overcome arises only if the robot controllers are required to exchange data. A measurable loss of time may occur due to the wait-talk-wait communication cycle. This is most readily solved by minimizing the number of communications, where possible, by combining transmissions and by minimizing the amount of data transmitted.

Compatibility of communication protocols between the controllers must be assured. Normally this occurs naturally if the robots are all the same model or are manufactured by the same company. If widely different machines are to be selected for their specific operating features, however, their protocol scheme should be an important item in the selection process.

THE ADEC THREE-ROBOT DEMONSTRATION CELL

The IBM 7535 robot's function was to assemble circuit breakers. The assembly process consisted of the robot's individually picking up three parts in its multiple gripper and forming a subassembly. It then placed the three-part subassembly into an empty housing at the assembly station of an indexing conveyor. The conveyor then indexed the housing through an electrical test station, after which the robot placed a lid on the housing at the closing station on the conveyor. Finally, the IBM robot removed the circuit breaker assembly to a holding pallet for access by the Seiko robot.

The Seiko PN-700 robot functioned as a pick-and-place device to move the finished circuit breaker from the holding pallet to a shuttle that would transfer it to the Hitachi robot for disassembly. The Seiko's work envelope was almost entire-

TABLE 1
OPERATING SYSTEM OUTLINE

IBM 7535	Hitachi PW10	Seiko NP-700
Pick up three parts from feeders*	Wait*	Transfer circuit breaker from holding pallet to shuttle*
Place part subassembly in housing*	Remove and place lid in holding pallet*	Wait
Pick up lid from holding pallet*	Pick up parts and housing from shuttle	Wait
Place lid on circuit breaker*	Place housing on conveyor*	Wait
Pick up and place complete circuit breaker on pallet*	Return parts to feeders	Wait*

* Handshake signal present in this step.

ly within the work envelope of the larger IBM robot.

The Hitachi PW10 robot disassembled the breaker and recycled the parts for future assemblies. First it removed the lid and placed it on a holding pallet. Then it picked up the three-part subassembly (as a unit) and the empty housing. It placed the housing on the conveyor at the input station and finally placed each of the three parts back into the proper feeder, depending on the model of the breaker. All of the Hitachi programmed points were within the work envelope of the IBM except for the pickup point for the incoming housing on the shuttle.

The preceding description is summarized in Table 1, which indicates that at least two robots are operating at all times.

The fact that two robots are always in motion indicates that the problems of peripheral device location and workload optimization were efficiently solved. Because the Seiko was operated by the Hitachi controller, only two handshakes were required—one for the IBM-Hitachi CAC, and the other for the IBM-Seiko CAC.

CONCLUSION

The most important recommendation that can be offered from this project is to carefully evaluate the planned assembly process and decide whether a multi-arm cell is the best solution.

The following questions will be helpful in this evaluation:

- Can two robots perform different assembly operations at the same assembly station more efficiently than two single robot cells?
- Is space available for robots and peripheral devices in one workcell?
- If different robot functions are required and if data must be transmitted between them, are the controllers similar enough so that communication is simple?
- Can the system be optimized so all robots are working a majority of the time?

Answering these questions and evaluating system needs should yield a clear indication as to whether a multi-arm robot cell is the best selection for a given application.

Brian Wade is an applications engineer and **Roger H. Clarke** is department manager for Gulf+Western Advanced Development and Engineering Center.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

4	14	24
Excellent	Good	Fair

ANOTHER COMPLIANT MECHANICAL GRIPPER

Hal Harris
Harris Engineering Inc.
4120 N.W. 11th Avenue
Fort Lauderdale, FL 33309

As noted by Robert E. Parkin and Warren K. Hutchinson ("A Compliant Mechanical Gripper," May 1985 *Robotics Age*), the problem with most existing mechanical grippers used as robotic end effectors is the lack of compliance. The compliant gripper that Parker and Hutchinson devised is fascinating in its simplicity and ease of modification.

I have developed another form of compliant gripper, based on a different concept. An examination of a plane surface formed into a special ungula of a right circular cylinder, whose lateral area is described by $2\pi H$, reveals the design inspiration (Figure 1).

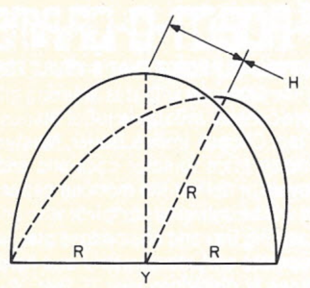


Figure 1. The gripper design was inspired by the plane surface formed into a special ungula of a right circular cylinder.

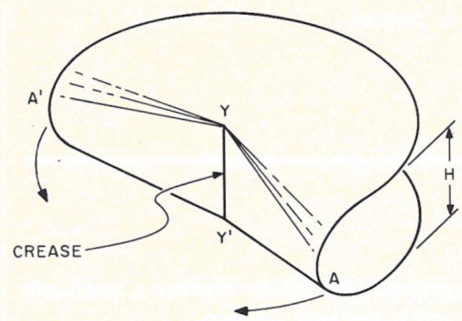


Figure 2. When the compound curvature of the plane area is folded, the fold rounded, and the surface Y–Y' creased, distance H changes proportionally to the squeeze force exerted at points A and A'.

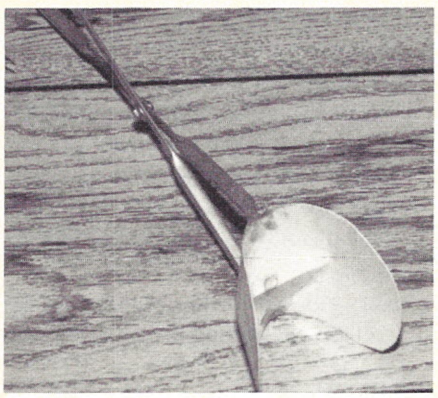


Photo 1. The gripper prototype is outfitted with scissors handles made of aluminum channel stock.

By taking the compound curvature of the plane area, rounding the fold, and dimpling the surface between Y and Y' into a crease (Figure 2), and applying pressure along the periphery at points A and A' in a squeezing fashion, H is decreased in a motion proportional to the squeeze force exerted at A and A'.

At this stage of the gripper's development, I was content with just activating the gripper by my thumb and index finger, and picking up odd objects. The next logical step was to devise some actuators. Attachments to points A and A' were constructed from solderless terminals by bending the two terminals (Figure 3) and gluing the "U" shape to A and A'. A means of squeezing these points with a simple mechanism became evident, and I built a scissors type construction out of two aluminum channels. Photo 1 shows the prototype with the scissors handles attached.

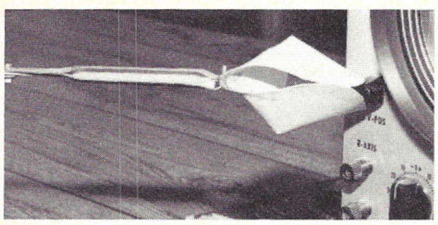


Photo 2. The gripper can close down on small objects, such as an oscilloscope knob.

This project can be duplicated in a hands-on experiment by simply cutting a piece of 0.015 in. (0.038 cm) cardboard in an approximate length-to-width ratio of 1.66, and after creasing it and squeezing the edges to form the gripper use it to pick up small items or tease the family cat. The device could find applications where an inexpensive, disposable end effector is required, and could be constructed of other materials such as thin stainless steel for use in liquids.

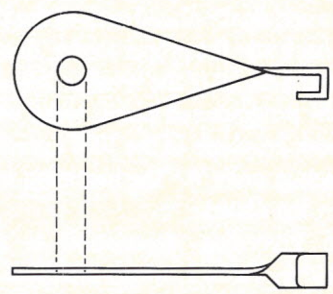


Figure 3. Two solderless terminals were bent and glued at points A and A' to serve as actuators.

Hal Harris owns an engineering firm and has been involved with electromechanical design for 25 years.

Reader Feedback

To rate this article, circle the appropriate number on the Reader Service card.

5	15	25
Excellent	Good	Fair

Edited by Stephanie vL Henkel

ROBOTICS NEWS FROM GREAT BRITAIN

While we were preoccupied with American, Japanese, Swedish, and Korean robots, British roboticists were going about their work with little fanfare but with considerable ingenuity. Two robotic devices have recently come to our attention, and even though neither is as yet on the market, both warrant some attention.

The Gadfly robot (Photo 1), presumably named for the long-nosed insect it resembles, has three pairs of telescopic legs that push on the corners of the triangular faceplate that holds its manipulator. The Gadfly's primary advantages are said to be rigidity and light weight. The version shown in the accompanying photo has two 6-axis force sensors; the robot's developers intend eventually to fit it with as many as 50 tactile sensors in addition to vision. It can be programmed to perform intricate tasks on irregular and delicate surfaces—like writing its name on an egg. The Gadfly is expected to find assembly applications.

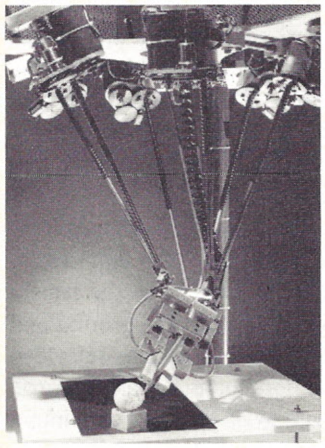


Photo 1. The Gadfly.

Photo 2. The Omnigripper.

The Omnigripper (Photo 2), said to be the first of its kind in the world, consists of two slightly separated "fingers." Each finger is made up of an array of 127 closely spaced telescopic pins that ride up and down independently of each other. Lowering the gripper over an object pushes some of the pins up, creating an indented configuration that custom fits the object to be lifted. The gripper's payload is 4.4 lbs. It is expected to prove handy in automated plants where robots need to handle a wide variety of parts in assembly operations. ■

RACCOON BUSTER

One of our readers has written to tell us of a toy he put to work. The gizmo he created has no foreseeable commercial applications, but we believe his story is worth sharing. Mike Rigsby of 2210 Camino Del Mar, Sanibel Island, Florida 33957, writes:

As a new resident of Sanibel Island, off southwest Florida, I encountered a problem: raccoons foraging in my garbage cans. My house is on pilings, and the cans stored underneath are open to animals but not exposed to rain. Harming the raccoons was unacceptable; metal cans don't survive the delicate touch of the trash collectors; and building a garbage shed, a popular solution, was not for me. I tried tying the lids on with heavy straps, but the raccoons turned the cans over and chewed on the plastic lids, destroying the containers and keeping my family up half the night.

I decided upon a robot trash sentry to scare the animals off, and I built one in two nights from supplies found in my workroom. Raccoon Buster is a modified Milton Bradley Big Trak™. It waits by the cans for intruders (anything within 3.5 ft.). When it detects a visitor it charges, firing its "laser cannon," a combination of noise and blue light, and then returns to its watch position.

I took a broken Polaroid sonar camera that wouldn't eject film and used small nuts and bolts to fasten it to the Big Trak 9 V battery compartment lid. To the top of the camera I fastened a microswitch, actuated by a raised lobe at the 3.5 ft. mark on the camera lens.

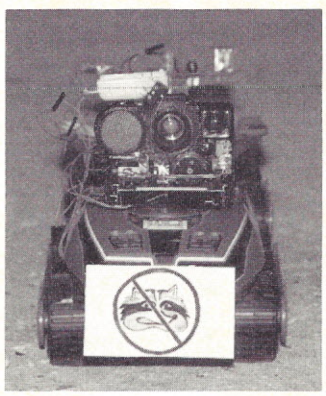


Photo 1. The Raccoon Buster.

By trial and error I found the place where, upon contact closure, autofocusing could be initiated. Closing this contact (Figure 1) caused the camera to focus and the lens to rotate toward the nearest object in front of the sonar unit. Releasing the contact returns the lens to the infinity position. With some auxiliary circuitry (Figure 2), I caused the lens to focus once every 90 seconds. The Polaroid requires a 5 V power supply, which I obtained from four D cell batteries mounted in a Robotix™ power supply box. A 7805 circuit supplied proper voltage to the camera. Two little levers in the camera must be held up or the camera refuses to focus. To fix these, I removed the battery and film from a film pack, sawed it into pieces, and slid the leftmost quarter of the pack into the camera.

The microswitch contact, normally open, needed to parallel "GO" on the Big Trak. This switch is part of an inexpensive pressboard arrangement and not easily paralleled at the source. I followed the leads to the main circuit board and soldered tiny wires to pins 22 and 12 of the largest in-

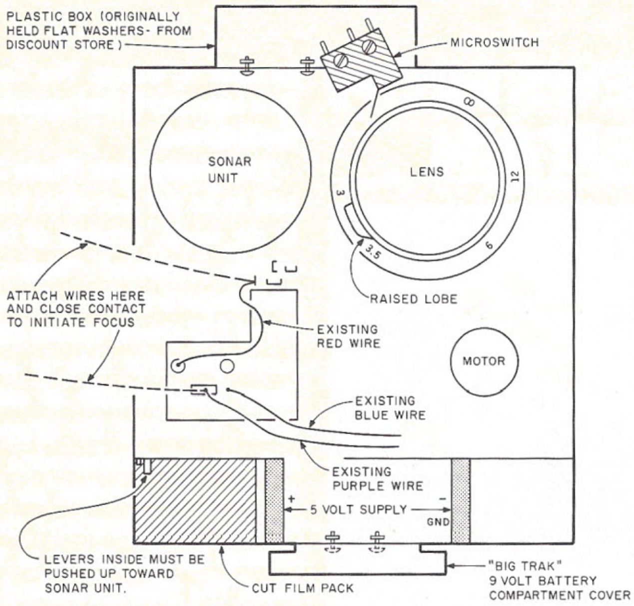


Figure 1.

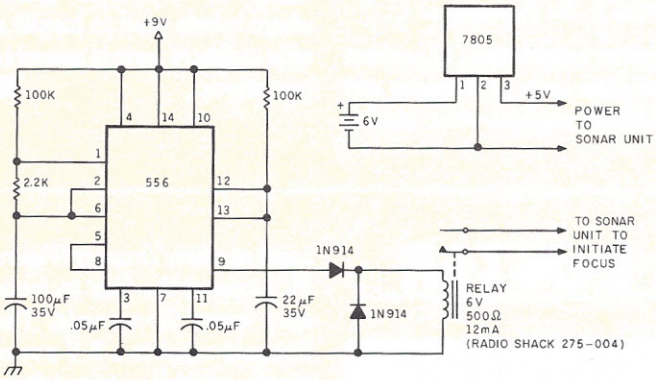


Figure 2.

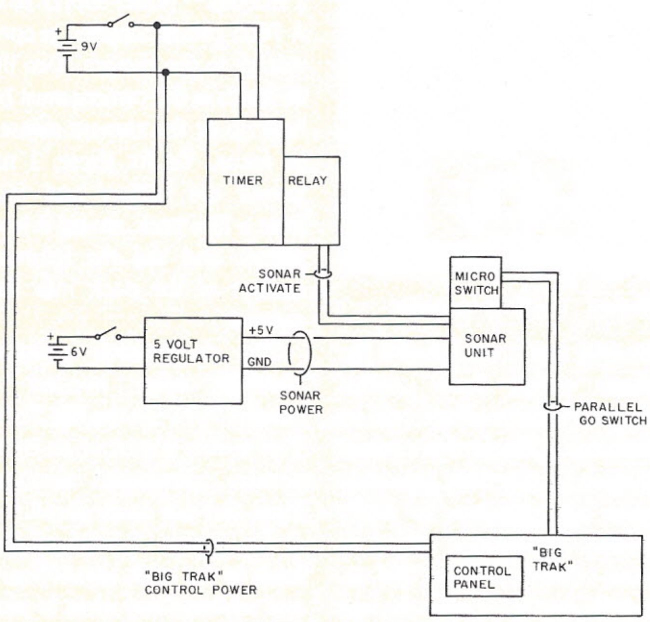


Figure 3.

tegrated circuit. I brought the Big Trak power supply out the side and tied it to the supply for the timer circuit. The Big Trak beeps every two or three minutes to let the user know it is powered but not doing anything. I brought the speaker wires out so I could silence the device if I wanted to, but for the most part I let it beep—anything that moves the raccoons is OK.

The suspension needed to be checked, for if the unit were to become front heavy the camera would look at the ground and think the world was saturated with raccoons. I could use small wire to tie the front axle into a position that would keep the Buster's nose up if that becomes necessary.

Operation is simple. I turn on the power to the sonar unit, turn on the Big Trak, and program it for a scare routine: five "laser" blasts, move forward four lengths, sit 30 seconds, five blasts, backward four lengths, five blasts. The "OUT" command normally activates the transporter, a dump trailer behind the main vehicle, but it could be used to activate a transmitter instead, allowing remote control of floodlights, alarms, or hidden cameras.

Although raccoons can be very aggressive and sometimes even try to face a human down, they cannot shake Raccoon Buster's courage—the Buster is unimpressed by growling and a show of teeth, and better yet, it can't hurt anything. ■

PEOPLE

► **Walter K. Weisel**, president of **Prab Robots Inc.**, has been named chief operating officer. He assumes his new position from John J. Wallace, who will remain with the company as chairman and CEO. Weisel was a founding member of the Robotic Industries Association and Robotics International.

► **Roger Gower**, former president of ITT's Qume subsidiary and most recently CEO and president of Miniscribe Corp., has joined **Intelledex** as president and CEO. Company founder and former president S. Stanley Mintz becomes chairman of the board and chief technical officer. Prior to his work at Qume, Gower was with Texas Instruments.

► **Al Barkovsky**, formerly vice president of marketing for **Silogic, Inc.**, has been named president. He succeeds Fred Braddock in that position. Barkovsky's previous work was with the Infonet Group of Computer Services Corp., National CSS, and IBM.

► **Gould Inc.** has named **Stuart A. Brown** general manager of its Motion Control Division. In addition to previous work for Gould, Brown has held positions at Century Electric, Inc., and GE.

► **Arnold F. Foess** has been named project sales engineer for **John Brown Automation Inc.** Foess's previous experience was with GM's Rochester Products Division and Gilman Engineering and Manufacturing Co.

► **Byron Walker** has been named Automotive Sales Manager for **American Technolo-**

gies Inc. Walker has served as director of the Midwest Robotic Center for ASEA, Inc. and has held positions at Unimation Incorporated and United Technologies.

► **Wilton A. Savage**, formerly director of financial analysis at **Warner & Swasey Co.**, has been made vice president for finance at that company. Savage, a graduate of W&S's Turning Division apprenticeship program, has held financial positions with Fairchild Camera, Texas Pipe Bending Co., and Bendix Corp.

► **Kulka Smith Inc.**, a North American Philips company, has appointed **James E. Cooper** director of marketing. Cooper was formerly with Amerace Corp., Control Products Div.

► **Cognex Corp.** has named two marketing managers to vice president: **Louis A. Laurent** is now VP of the Printing and Packaging Groups, and **Ian G. Morris** is VP of the Electronic and Industrial Business Groups. Laurent's previous experience was with Atex, Inc., Compugraphic, and Eastman Kodak. Morris has worked for Foxboro Corp. and Transitron.

MARKET RESEARCH

The U.S. robotics industry showed a strong rebound in 1984 after slowing down in late 1982 and 1983, according to a recent study conducted by the **Predicasts Industry Studies** division of **Business Trend Analysts**. The market is expected to continue to show long-term growth, reaching $1.8 billion by 1989 and $4.9 billion in 1995. The fastest growth will be in assembly robots, followed by coating and spray painting robots.

In 1984, the top 12 producers of industrial robots accounted for 86 percent of the market. In 1982, the same share was controlled by seven companies. Two years earlier that number was only two. The new report interprets the data as refuting the prediction popular several years ago that smaller producers would be overwhelmed by large conglomerates such as General Electric, Westinghouse, IBM, and General Motors. Although the robot industry's concentration is declining, 25 producers account for nearly 96 percent of the U.S. market while the remaining 4 percent is divided among more than 70 domestic and 50 foreign competitors.

EDUCATION

► The **University of Alabama** at Tuscaloosa has a new, $300,000 robotics lab that welcomes undergraduates as well as faculty and graduate students. Dr. Reggie Caudill, lab director, anticipates that the facility will be a resource for industry, helping, for example, manufacturers to evaluate computer software and to determine which, if any, robot to buy.

► The Manufacturing Engineering Dept. of **Boston University**'s College of Engineering is offering a new nine-course program that can lead to a master of engineering in manufacturing. The program includes courses in CAD/CAM/CAE, robotics, and integrated processing cells. The new courses were developed in part with funding from the Bay State Skills Corp., a state agency formed to enhance technology-oriented job skills.

► The **University of California—Los Angeles** extension school's Dept. of Engineering and Science is offering two new evening classes: Robotics and Robotics Laboratory. Robotics is an interdisciplinary course on theoretical and practical robotics. Robotics Laboratory is designed to provide experience in programming and operating three industrial robots.

► **Control Data Corp.** has developed a one-month program, Introduction to Robotics, to teach robotic applications, the robot work environment, the internal operations of a robot, robotics programming, and troubleshooting. The program will be offered first at Control Data Institutes in Chicago, Boston, Minneapolis, St. Paul, and St. Louis. The study can be undertaken as a continuing education course, as a component of the CDI's computer technology curriculum, or as part of an employer- or government-sponsored job retraining program.

CORPORATE NEWS

► **Gould Inc.** has announced its acquisition of **International Cybernetics Corp.** ICC, founded in 1982, designs, develops, and manufactures a line of flexible automation controllers and a broad spectrum of proprietary applications software. Under the terms of the agreement, ICC management, under the direction of ICC president Donald Jones, will continue to operate the firm. Jones will be responsible to John A. Blaeser, Gould executive vice president in charge of factory automation. Gould develops and manufactures defense, instrument, factory automation, and information systems, along with semiconductors and other electronic components.

► **Digital Equipment Corp.** and **Artificial Intelligence Corp.** have announced an agreement that enables Digital to manufacture, sell, and distribute Intellect™, AIC's natural language information management software. According to AIC, Intellect is being developed for the VAX™ family of computers. Intellect will operate under Digital's VMS™ operating system and will interface to Digital's VAX RDB relational database software.

► **Xerox Corp.**'s Special Business Div. has signed a major OEM agreement as a value-added remarketer for **Cadlinc**'s engineering workstations and mechanical design and drafting software. Xerox will re-sell, under its private label, Cadlinc mechanical workstations and software, modified to fit Xerox's target markets. Customers will receive training and support directly from Xerox.

► **Integrated Computers, Inc.** has reached an agreement with **Sohio Engineered Products** to market and support an automated process control software system developed by Sohio. The agreement grants an exclusive license to market and sublicense the software for use with Digital Equipment Co.'s MicroVAX computers in the U.S. and Canada.

► A multiyear technology and product exchange covering 16-bit single-chip microcomputers has been disclosed by **Intel Corp.**, **N.V. Philips**, and **Signetics Corp.**, a Philips company. Signetics/Philips will be alternate sources for Intel's MCS-96 family of microcontrollers. The agreement is an outgrowth of prior accords between the companies. Intel announced also first customer shipments of its iPSC family of concurrent computers. The initial customers were Yale University and Oak Ridge National Laboratories. Additional computers will be shipped in the near future to the Research Institute for Advanced Computer Science and the Supercomputing Research Center.

► **EIC/Intelligence, Inc.** has acquired the Robotics Information (RBOT) electronic database from **Cincinnati Milacron, Inc.** The RBOT file contains some 8500 abstracts and citations to documents covering all aspects of robotics and automation. Coverage dates from 1973 through the present, making RBOT the largest collection of robotics data available on line. It will be added to EIC's own Robomatix database and will be available through Bibliographical Retrieval Service.

► **General Electric Co.** has announced that its **Calma** subsidiary intends to hire more than 200 engineers at its research and development centers in California and Texas. The figure represents nearly a 50 percent increase in Calma's R&D staff. The new positions will support increased investment in software and hardware development for GE Calma CAD/CAM/CAE system products.

► Dwight Carlson, president and CEO of **Perceptron**, has announced the firm's closing of its final, pre-public round of private financing in which the company raised equity totaling $9 million. Participating in the financing were the company's current investors, joined by seven new ones. Carlson said the funds raised would be used to meet increasing demands for the firm's vision systems, to expand into new U.S. and European markets, and to increase product development efforts.

► **EDS Technologies, Inc.—Robotics Division**, formerly WMI Robot Systems, Inc., has entered into an exclusive agreement with **Horyu Control Engineering Co. Ltd.** of Japan to sell and service Horyu's complete line of robot controllers in the U.S., Canada, and South America.

► The first industrial robot exported by a Korean company has been shipped by **Daewoo Heavy Industries Ltd.** to **Automaker Inc.** The arc-welding robot, developed and built by Daewoo, was one of two ordered by the Houston firm. **Robotics and Automation Control Inc.** has also ordered a Daewoo robot. Daewoo is the only Korean company currently manufacturing industrial robots. The export orders were signed in June at the Robots 9 convention.

► **Proctor & Gamble** has invested $4 million in **Teknowledge Inc.** through a stock purchase. Previous equity investments have been made by GM, FMC, Framatone & Cie, and Elf Acquitaine over the past 2½ years. Teknowledge develops, markets, and supports software for expert systems.

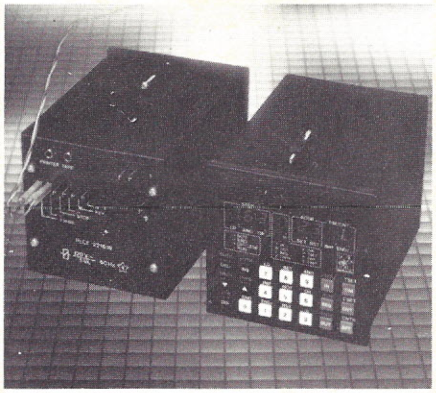
► **Belcan Corp.** has purchased the outstanding shares of **Multicon, Inc.**, a systems integrator for robotics and machine vision. Under the terms of the sale, Multicon will continue to operate as a separate entity. Belcan offers services ranging from facilities and machine design to CAD and computer simulation.

New Products

Programmable Controller for Long Distance Applications

A new programmable controller features a unique two-wire transmission system that provides connections to control units up to 10 miles away without using multiplex racks, special cables, or duplicate wiring. The Micro-PLCF from Electromatic Controls Corp. is available with 1, 2, 4, 8, or 16 Dupline® F-System I/O plug-in modules that connect directly to the transmission line at any point along the 10-mile run.

A simplified programming language and logical keyboard design allow the controller to be programmed by anyone familiar with simple ladder diagrams. Additional features include a single I/O plug on the back of the unit, standard relay functions, and 64 integral registers that correspond to auxiliary relays in relay control.



For more information, contact: Mike Meurer, Electromatic Controls Corp., 2495 Pembroke Ave., Hoffman Estates, IL 60195-2010, telephone (312) 882-5757. Circle 60

Video Training Program for a Programmable Controller Line

The PLC-2 training package from Allen-Bradley contains 13 modules suitable for introductory as well as refresher use of the company's line of programmable controllers. The modules include one video tape, 10 student workbooks, one proctor's guide, 10 job guides (only with certain modules), and 10 maintenance notebooks (optional). They can be ordered and used individually, in processor-specific sets, or as a complete package.

For more information, contact: Mike Moore, Marketing Publicity, Allen-Bradley Co., Industrial Computer Group, 747 Alpha Dr., Cleveland, OH 44143.

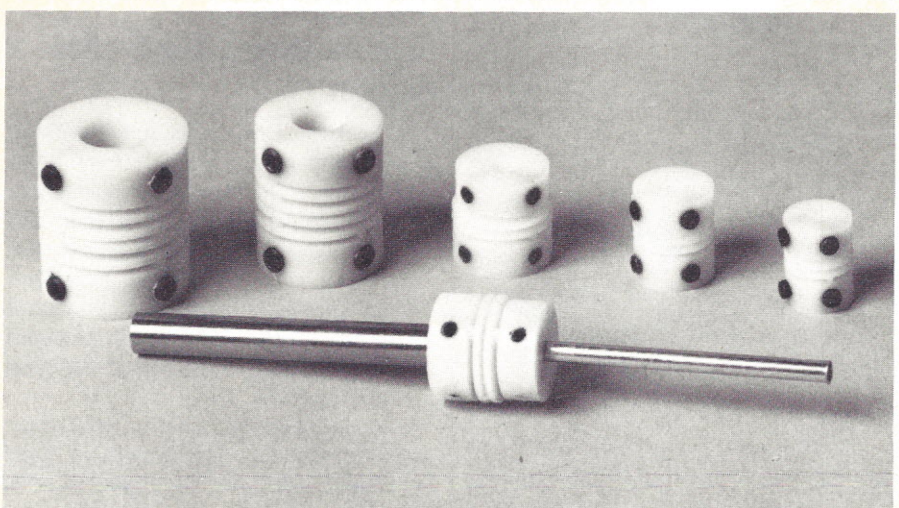
Circle 61

High-Performance Shaft Couplings

Strong, "no wind-up" shaft couplings that accomodate both axial and angular misalignment are available with metric and standard i.d.s from 0.079–0.394 in. from Micro Mo Electronics Inc. Step-up/step-down models also are available in molded polyacetal plastic with or without glass reinforcing fibers.

They are suitable for applications requiring inexpensive and reliable methods of tightly linking shafts, controls, tuning systems, or other connections requiring high power transmission efficiencies. Maximum angular displacement for the UJ model is 9 degrees; for the GJ series, 10–12 degrees, depending upon the model. Allowable axial displacement for the UJ series is up to 0.03 in.; for GJ, up to 0.05 in. Continuous torque values range from 35 oz-in. to over 420 oz-in.

For more information, contact: Steve O'Neil, Micro Mo Electronics Inc., 742 2nd Ave. South, St. Petersburg, FL 33701, telephone (813) 822-2529. Circle 62



Multiport Controllers Offer Six Modes of Operation

The H-Series multiport controller from Bay Technical Associates is a user-programmable, multi-function device that allows RS-232 serial port expansion/sharing, time division multiplexing, and message multiplexing. Model 528H features one host port and eight peripheral ports. The currently available model can be used to adapt small computers to industrial process-control and data-gathering applications.

There are six modes of operation: full duplex communication; all messages from all ports; single message from all ports; all messages from a selected port; single messages from a selected port; and time-division multiplexing.

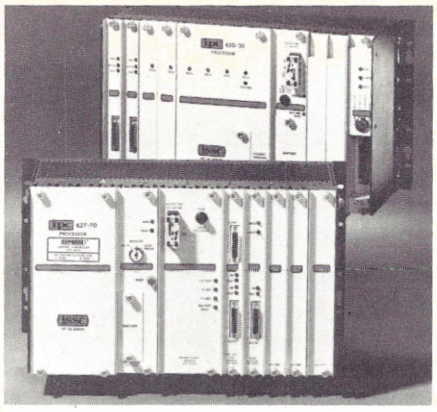
For more information, contact: Bay Technical Associates, Inc., Hwy 603, PO Box 387, Bay St. Louis, MS 39520, telephone (601) 467-8231. Circle 63

New Products

Support Controller For an Industrial Microcomputer

Honeywell's IPC 626 Support Controller™ integrates self-teach machine diagnostics, statistical reporting, and graphic displays to create the operator interface. It replaces software programming the way programmable controllers replaced hardwired logic, the company says.

Intelligent modules, dedicated to segmented tasks, permit each module to perform its tasks independently of the IPC 620 programmable controller's logic processing and memory. Windowing is also available to report an early warning of faults in the machinery during running time, reducing repair time by displaying on the console the precise activity that caused the fault regardless of the sequence in which it occurred. The entire machine need not be examined by the repair team.



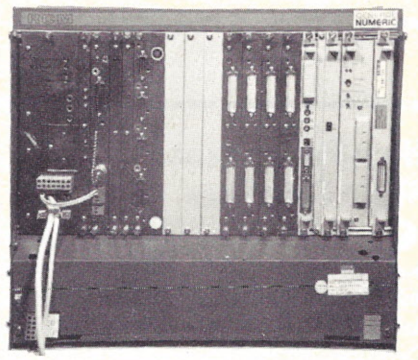
For more information, contact: Larry Worth, Honeywell Inc., Industrial Programmable Control Div., 435 W. Philadelphia St., York, PA 17404, telephone (717) 848-1151. Circle 64

Robot Control Has Integrated PC

General Numeric has introduced the RCM 1.1 robot control featuring point-to-point control of up to six axes, variable corner in-position check function, and user memory for up to 1600 space points.

A powerful programmable controller allows the control system to communicate with other manufacturing elements on the production floor, and frees the control of routine functions. The RCM 1.1 control functions are designed for loading/unloading of machines, spot welding, simple assembly tasks, and palletizing.

For more information, contact: Gene Bielinski, Robotic Applications Dept., or Beau Remien, Marketing, General Numeric Corp., 390 Kent Ave., Elk Grove Village, IL 60007, telephone (312) 640-1595.



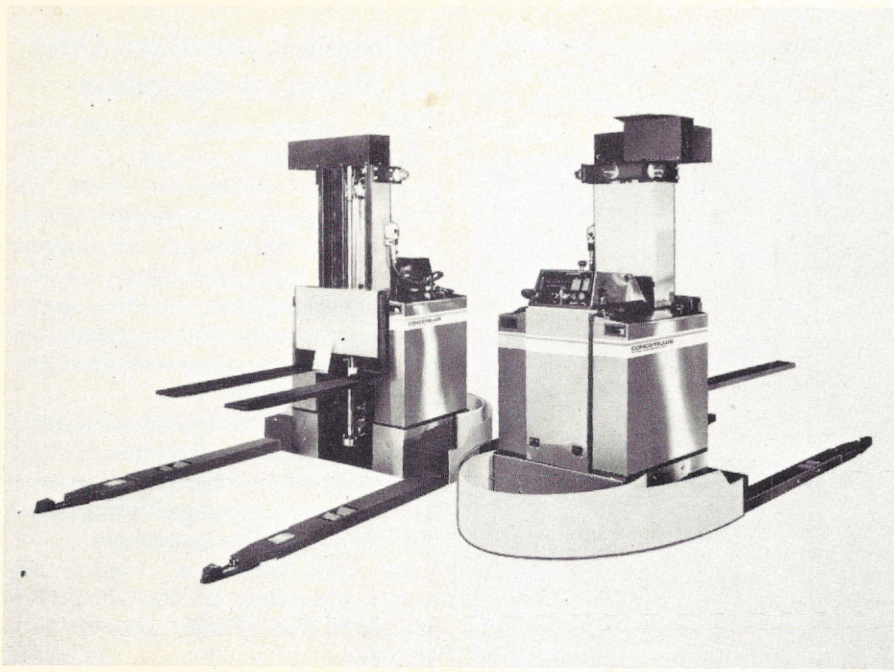
Circle 66

"Standard" AGV Systems

Conco-Tellus has announced the availability of 10 different standard automatic guided vehicle systems that can, according to the company, be easily integrated into most operations. The UHCS Series, one of the 10 basic units, comes equipped with floor level, forged forks. The AGVs are designed to pick up, transport, and deposit 4 by 4 ft. pallet loads up to 4000 lbs. to levels up to 55 in. with insured lifting accuracy of $\pm 1/16$ in. at any height, and repetitive stopping accuracy of ± 0.39 in. Their narrow configuration, ability to turn on their own axes, and bi-directional capabilities render them useful in tight spots.

For more information, contact: Conco-Tellus, AGVS, PO Box 160, Mendota, IL 61342, telephone (815) 539-3450.

Circle 65



Multifunctional Manufacturing Controller System

A multifunctional manufacturing controller system is now available from LASR Robotics, Inc. The expandable multiple-axis controller (EMAC) supports up to ten parallel 4 MHz processors. It can simultaneously control several robots and their pneumatic, hydraulic, and sensing equipment. Because of its modular design, EMAC may be upgraded by adding ports or motors without disrupting the existing system.

For more information, contact: Rob Turner, LASR Robotics, Inc., 4116 Walney Rd., Suite D, Chantilly, VA 22021, telephone (703) 631-9888. Circle 67

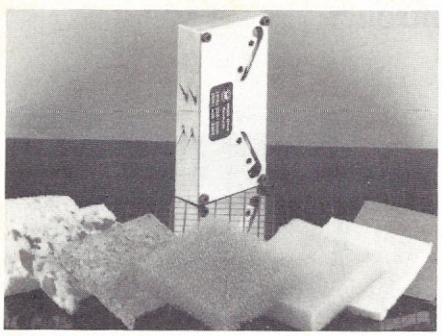
New Products

Needled Pneumatic End Effector

Stock Drive Products is offering an end effector that uses two sets of angularly positioned needles designed to grip porous sheet materials including cork, sponges, urethane and styrofoam, and cardboard packaging materials. The AG Series Model 020 was designed for applications where conventional suction cup devices are not appropriate. One unit can handle porous sheet materials weighing up to approximately 9 lbs., depending on material density.

The 1.181 mm diameter stainless steel needles project from the gripper at a 120 degree angle and can be adjusted in length up to 0.59 in. Each of the two sets of needles is located 0.394 in. apart along the bottom surface of a machined aluminum rectangular housing 4.37 in. wide by 0.984 in. deep by 2.56 in. high. The unit operates on standard 80 psi shop air.

For more information, contact: Herb Arum, Stock Drive Products, 2101 Jericho Tpk., New Hyde Park, NY 11040, telephone (516) 328-3330. Circle 68



Robotics Database

A newly available database from The Robotics Database uses the Ashton-Tate dBase II management system for the IBM PC to provide information about 200 automated systems titles on robotics, education, and training. Each entry contains a citation, key words, a narrative description, and essential quotes from the original material. Sources can be found by entering the author, title, date of publication, or a key word. Updated disks will be periodically available, the company says.

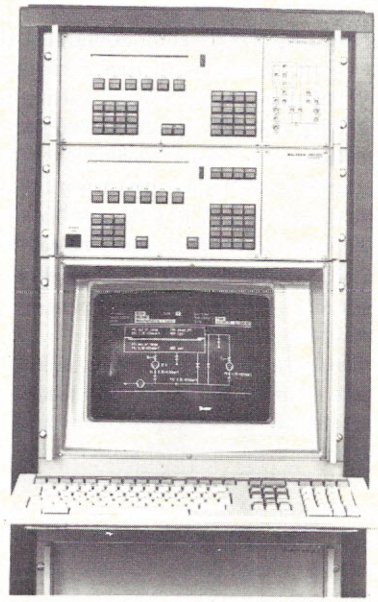
For more information, contact: The Robotics Database, PO Box 3004-17, Corvallis, OR 97339. Circle 70

Coating Systems Controller

Balzers has introduced a fully automatic programmable controller for coating process systems. The BPU420 features modular hardware and software and uses standard SECS I and II for external communications. It provides pushbutton control of an entire process run; programming possibilities include 100 layer modules and up to 16 source modules.

Designed with separate central processing units for the vacuum and gas system, deposition controller, and optical monitoring package, the system control handles the simultaneous operation of up to three sources. Quartz crystal measurement is based on the heterodyne principle with less than 100 ms cycle time and 0.1 Å/sec rate resolution.

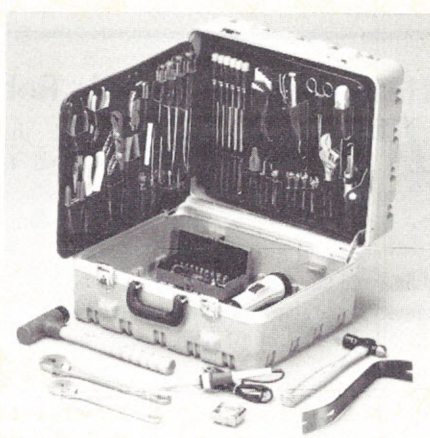
For more information, contact: Johnny Hagen, Product Manager, Balzers, 8 Sagamore Park Rd., Hudson, NH 03051, telephone (603) 889-6888. Circle 69



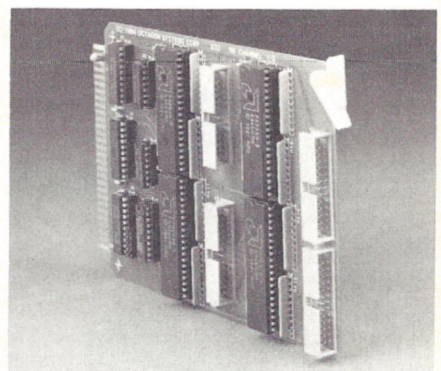
Tool Kit for Industrial Robotics

Jensen Tools Inc. has introduced a tool kit designed for the installation and maintenance of industrial robots. The JTK-58 Robotic Technician's Maintenance Kit supports hydraulic, electric, and pneumatic drive systems, as well as servo- and non-servo-controlled equipment. The kit offers a unique tool selection, adaptability to either English or metric measurement, and a rugged, high-density polyethylene case.

For more information, contact: Jensen Tools Inc., 7815 S. 46th St., Phoenix, AZ 85044, telephone (602) 968-6231. Circle 71



STD Bus Card with 96 Channels of I/O



Designers of STD bus systems can now have up to 96 channels of digital I/O on one card by using Octagon Systems' new 832 card. The high density of the 832 TTL I/O card may reduce the system card count. Channels can be configured by software as inputs or outputs in groups of 4 or 8 channels. All 96 channels may be nonlatched inputs or latched outputs, and up to 64 channels may be latched inputs. Four 26-pin connectors connect the 832 to termination. The 832 is processor-independent.

For more information, contact: Octagon Systems Corp., 6501 W. 91st Ave., Westminster, CO 80030, telephone (303) 426-8540. Circle 72

New Products

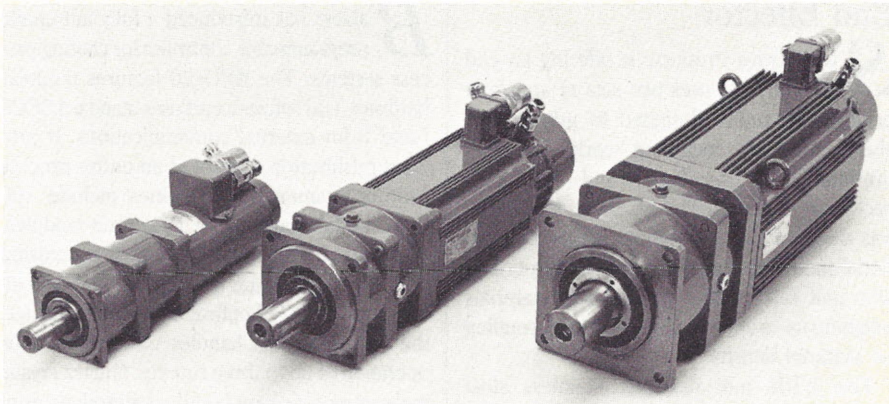
Network Control Module

The system 600 Network Control Module from International Imaging Systems provides high-speed point-to-point exchange of large image data files in a distributed processing environment. Used in conjunction with the system 600 Core Module, the network control module supports VAX 11 series and Masscomp (68000-based) computers, operating with VHS or UNIX respectively, as well as networks incorporating a 68000 microprocessor-based work station.

Providing a 16-bit parallel transfer link, the module contributes to rapid, economical network formation as well as to smooth expansion from single- to multiple-host network configurations, the company says. It facilitates compartmentalization of tasks such as I/O, image enhancement, and geometric transformation, and allows integration of multiple data sets.

For more information, contact: Steve Lytle, International Imaging Systems, 1500 Buckeye Dr., Milpitas, CA 95035, telephone (408) 262-4444. Circle 73

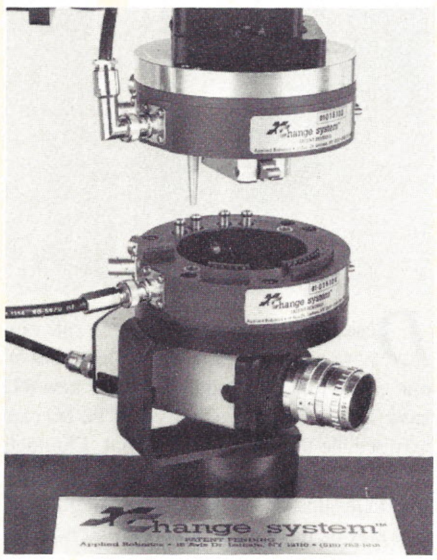
AC Servo Gearmotors



A series of high-torque, high-performance AC servo gearmotors has been introduced by Indramat. Six models are available, providing a continuous torque from 68–2413 in.-lbs at closed-loop operating speeds up to 2000 rpm. The gearmotors use Indramat's MAC series of AC servo motors as a base, and include a wide range of cyclo and planetary gear reductions. The brushless design allows maintenance-free operation. The motors are supplied completely assembled and tested with heavy-duty radial load bearings. Pinion gears may be mounted directly to the output shaft.

For more information, contact: Robert P. Brennan, Indramat, 255 Mittel Dr., Wood Dale, IL 60191, telephone (312) 860-1010.
Circle 74

Correction

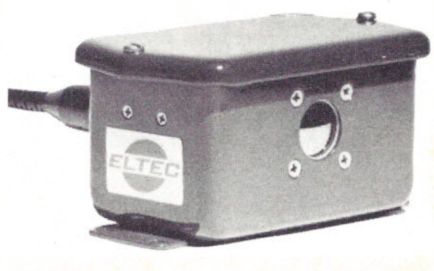


The Robot Hand Exchange System new product information that appeared on page 36 of the September issue carried an incorrect photo. Pictured above is the XChange Horizon™ from Applied Robotics, Inc.
Circle 76

Passive Infrared Industrial Controller

The IR-EYE™ Model 824 controller is designed to sense moving objects at a distance. The device, available from Eltec Instruments, Inc., senses the natural thermal radiation emitted by a passing object, converting it to an electrical signal that activates a relay closure rated at 120 V and 1 amp. The controller operates on 20–28 VAC (28–40 VDC) and draws less than 85 mA. Sensor gain and relay hold times are externally adjustable.

For more information, contact: Eltec Instruments, Inc., PO Box 9610, Daytona Beach, FL 32020, telephone (800) 874-7780.



Circle 75

Heavy-Duty All-Electric Robots

Roberts Corp. has introduced the Roberts/Motoman Model L-60 and its companion, the Model L-50. The robots have been designed for heavy-duty part handling, assembly, and sealing operations. Model L-50 has a maximum payload of 110 lbs and a maximum radial reach of 73.4 in. Model L-60 has a radial reach of 61.6 in. and a maximum payload of 132 lbs including gripper.

All six axes of both robots are positioned by high-torque electric servo motors. The robots position at rates of up to 150 degrees per second. Oversized drive train components, precision ball screws, and rigid steel construction improve the operating life of these robots and also contribute to the ±0.0102 in. repeatability. The compact wrist of both models offers three degrees of freedom; it bends 200 degrees and twists and rotates 360 degrees.

For more information, contact: Roberts Corp., PO Box 13160, Lansing, MI 48901, telephone (517) 371-2460. Circle 77

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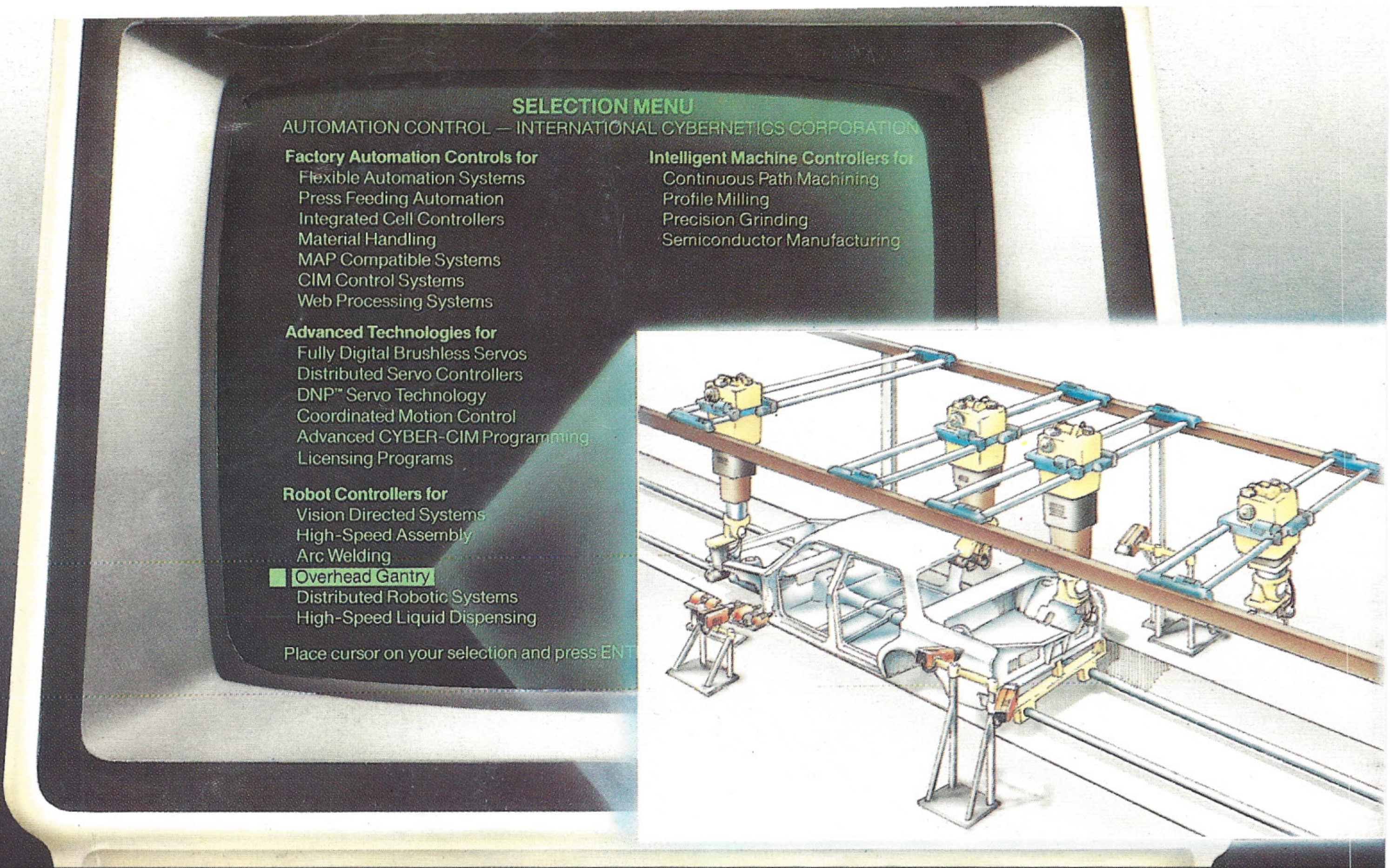
- Sensors for Process Control
- Sensors in Consumer Electronics
- Sensors in Robotics
  - Touch Sensors
  - Vision
- Temperature
- Vibration

Deadline for submission of abstracts has been extended to November 15, 1985.

Send a 150- to 200-word abstract and short biography to: Roberta Toth, Technical Editor, Sensors, Strand Building, 174 Concord Street, Peterborough, NH 03458, (603) 924-7261.

For information about exhibiting at SENSORS EXPO, contact: Ginny Rae or Susan Reuter, Expocon Management Associates, Inc., 3695 Post Road, Southport, CT 06490, (203) 259-5734.



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